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OUTLINE OF THE GEOLOGY OF NATURAL GAS IN THE UNITED STATES.

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GEOGRAPHIC DISTRIBUTION OF GAS FIELDS.

Natural gas is known in greater or less quantity in twenty-six states of the United States, but only twenty-three of these are deemed important enough to have been listed on a map published by David T. Day.[1]

The natural gas fields of the United States, in order of their estimated areas, are there enumerated in square miles, as follows:

Pennsylvania	2,730
Indiana	2,460
West Virginia	1,000
New York	550
Oklahoma	500
California	310
Kentucky	290
Ohio	275
Kansas	260
Texas	130
Wyoming	120
Louisiana	110
Arkansas	100

[1] David T. Day, "Known Producing Oil and Gas Fields of the United States in 1908," *Min. Res. U. S.*, 1908, Pt. 2, Pl. 1.

Colorado	80
South Dakota	80
Missouri	70
Washington	70
Illinois	50
Michigan	40
Montana	40
Utah	40
Alabama	40
Oregon	20
Total	9,365

The correspondence in geographic distribution between areas of gas production and those of oil production is a very interesting point geologically. The most important gas-producing areas are commonly classified into five regions:

1. Appalachian region, which includes the fields of New York, Pennsylvania, southeastern Ohio, West Virginia, Kentucky and Alabama.
2. Trenton rock region, or Ohio-Indiana field.
3. Clinton sand region, or Central Ohio field.
4. Mid-Continent or Kansas-Oklahoma field.
5. Caddo field in northwestern Louisiana.

PRODUCTION OF NATURAL GAS IN THE UNITED STATES.

In order of its value, gas production in the producing states ranked in 1910 as follows:[1]

West Virginia	$28,451,907
Pennsylvania	18,010,796
Ohio	9,367,347
Oklahoma	6,731,770
Kansas	4,854,534
Alabama, Texas and Louisiana	1,873,090
New York	1,418,767
Indiana	1,192,418
California	800,714
Illinois	687,726
Kentucky	407,689
Arkansas, Wyoming and Colorado	295,858
South Dakota	16,984
Missouri	10,496

[1] David T. Day, *Min. Res. U. S.*, 1911, U. S. Geol. Survey, 1912, p. 283.

North Dakota	5,738
Michigan	1,330
Tennessee	300
Iowa	70
Total	$74,127,534

In the same year 508,364,021,000 cubic feet of gas were produced, coming from the twenty-three states, in the following order of importance as follows:[1]

West Virginia	207,112,576,000
Pennsylvania	104,018,296,000
Oklahoma	67,275,608,000
Ohio	49,449,749,000
Kansas	38,799,406,000[2]
Louisiana and Alabama	9,786,041,000
Illinois	6,762,361,000
California	6,389,820,000
Texas	5,503,393,000
New York	5,239,915,000
Indiana	4,365,339,000
Arkansas, Colorado and Wyoming	2,293,662,000
Kentucky	1,275,397,000
Missouri	50,315,000
South Dakota	25,547,000
North Dakota	13,526,000
Michigan	1,730,000
Tennessee	1,200,000
Iowa	140,000
Total	508,364,021,000

On December 31, 1911, there were 28,428 wells in the United States from which natural gas was being produced. It was sold at prices ranging from one cent per 1,000 cubic feet at certain Oklahoma wells, to an average price of 76 cents per 1,000 cubic feet in Michigan. Of the gas produced 40 per cent. is used for domestic purposes and 60 per cent. for manufacturing and industrial purposes. About 11,000,000 acres of land were controlled for the gas rights. In the following descriptions by states, the figures giving number and depths of wells are taken largely from Doctor Day's reports in *Mineral Resources of the United States.*

[1] *Loc. cit.*, p. 284.

[2] Includes gas piped from Kansas and consumed in Missouri.

DESCRIPTION OF INDIVIDUAL FIELDS.

Description of New York Fields.—In New York State the natural gas produced comes from the Corniferous limestone of the lower Devonian system, and from the Guelph limestone, Niagara limestone, Medina sandstone and Trenton limestone of the Silurian; also from the Potsdam sandstone of the Cambrian system. Some of these formations furnish but small quantities of gas.

According to Oliphant,[1] the greatest known commercial gas pressure, 1,500 pounds to the square inch, has been found in the lowest beds of Potsdam sandstone of New York State, where it rests upon the granite.

The gas production of New York State is confined to sixteen counties in the western half of the state. The wells range in depth from 150 to 3,000 feet. In general the geological structure may be said to be monoclinal, but distinct anticlines exist along the southern border of the State.

Description of Pennsylvania Fields.—In Pennsylvania the natural gas is limited to the western and northwestern third of the State, west of the Allegheny Mountains, where the strata are comparatively undisturbed. The known productive horizons are more numerous than in any other state and they extend from the Conemaugh formation or the Lower Barren coal measures in the Carboniferous system down to the middle Devonian, with the certainty that undiscovered horizons exist below, which will at some future time be proved productive. The known producing sands in Pennsylvania are as follows, the figures indicating roughly the approximate average depth of the sand below the horizon of the Pittsburgh coal bed:

Carboniferous system (Pennsylvanian).	
Conemaugh formation or Lower Barren measures.	
Hurry-up sand	400
Allegheny formation or Lower Productive measures.	
Second Cow Run sand or Freeport sandstone	650
Gas sand	750
Pottsville formation.	
Johnson Run sand or Homewood sandstone	900

[1] F. H. Oliphant, "Catalogue of Metric Metal Works for 1909," p. 38.

Upper Salt sand or Upper Conoquenessing sand	950
Middle Salt sand or Lower Conoquenessing sand	1,050
Lower Salt sand, Maxon sand or Sharon conglomerate	1,130
Sub-carboniferous system (Mississippian).	
Pocono formation.	
Big Injun or Sub-Olean sand	1,350
Upper Devonian system.	
Catskill formation.	
Upper gas sand	1,550
Berea, Thirty-foot or Butler gas sand	1,750
Murraysville sand	1,800
First, Gantz, or Hundred-foot sand	1,850
Fifty-foot sand	1,900
Second or Ninevah Thirty-foot sand	2,000
Gray, Gordon Stray or Boulder sand	2,070
Third or Gordon sand	2,130
Fourth sand	2,200
Fifth sand	2,250
Bayard sand	2,400
Chemung formation.	
Elizabeth or Sixth sand	2,600
Warren First sand	2,700
Warren Second sand	2,800
Tiona sand	2,900
Speechley sand	3,000
Balltown or Cherry Grove sand	3,120
Sheffield or Cooper sand	3,320
Bradford sand	3,430
Second Bradford sand	3,480
Elk sand	3,650
Kane sand	3,770

The figures for the depths of the foregoing sands are in part taken from tables compiled by I. C. White and by F. H. Oliphant, and are in part estimated by the present writer. Other formations, which are not yet productive in Pennsylvania, but which may be expected to produce gas on deeper drilling, are the Corniferous limestone and Oriskany sandstone of the Devonian system, the Guelph, Niagara, Clinton and Trenton limestones and Medina sandstone of the Silurian system, and the Potsdam sandstone of the Corniferous, but these formations are all of great depth in western Pennsylvania and may not be drilled for many years. The Corniferous, in Washington County, has been reached at a total depth of 6,000 feet.

At the close of 1911 there were 10,809 producing gas wells in

Pennsylvania.[1] The wells were situated in twenty-three counties and the depths ranged from 300 feet to over 3,450 feet.

Description of West Virginia Fields.—The natural gas fields of West Virginia are situated in the northwest half of the state in thirty-one different counties. The total number of producing gas wells at the end of 1911 was 4,755. The depth was from 500 to 4,000 feet. In West Virginia the productive formations are substantially the same as those in Pennsylvania, but the thicknesses are greater and hence no productive formation has ever been reached below the Elizabeth sand, except in about two wells, which found gas at a horizon believed equivalent to the Speechley sand.

In addition to the formations mentioned, the Pittsburgh sand, Connellsville sandstone, Morgantown sandstone and the Dunkard sand of the Conemaugh formation are productive. The intervals below the Pittsburgh coal are all greater in West Virginia than in Pennsylvania. Both in Pennsylvania and West Virginia the gas fields owe their accumulation mainly to the existence of alternating anticlines and synclines, which traverse the states from northeast to southwest. The best fields are situated on the broadest and most prominent anticlines west of the Allegheny Mountains.

Description of Kentucky Fields.—In Kentucky the gas is situated mostly in the northeastern part of the state, although a few fields exist along the Ohio River in northwestern Kentucky. At the close of the year 1911, Kentucky had 252 producing wells. The productive formations in this state consist of the Sharon conglomerate, belonging to the Pottsville formation, the Big Injun and Berea sands of the Pocono, the Devonian shales and the Trenton limestone. Although the geological structure has not been studied in detail except locally, the fields apparently owe their accummulation in most cases to the existence of anticlinal structure.

Description of Ohio Fields.—In Ohio there are three distinct oil and gas regions, corresponding with distinct geological conditions. In northwestern Ohio is the Trenton limestone field,

[1] David T. Day, *op. cit.*

which constitutes a portion of the Ohio-Indiana field, and owes its existence to a marked doming and broadening of the Cincinnati anticline.

The second subdivision of the Ohio fields consists of the Clinton sand development, which forms a belt parallel with the Cincinnati anticline on the eastern side of it, extending from western Ontario southward nearly to the Ohio River. The existence of gas in this formation is due to the fact that the Clinton sand rises and dies out to the west about 100 miles east of the Trenton lime-

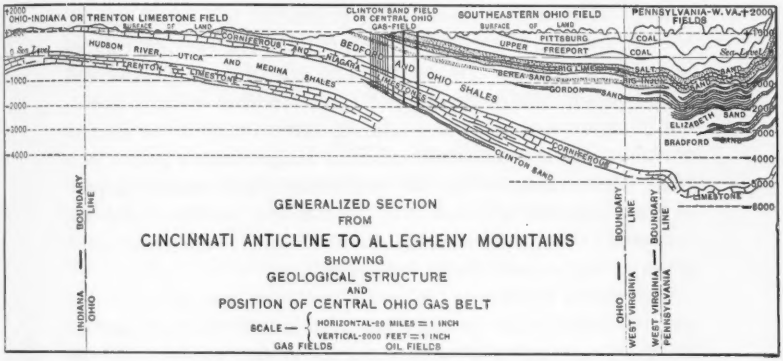


FIG. 42. Generalized cross-section from Cincinnati anticline to Allegheny Mountains, showing relative positions and geological structure of the various Ohio and Pennsylvania gas fields.

stone fields. The large gas fields are found in the highest portion of the Clinton sand.

The third subdivision in Ohio consists of the southeastern Ohio fields, covering a number of counties between the Clinton sand fields and Ohio River, and forming a continuation of the West Virginia development, being associated with anticlinal, synclinal, monoclinal and terrace structures.

Natural gas in Ohio comes from 41 counties. At the close of 1911 there were 4,717 wells in operation, the depths ranging from 240 to 3,450 feet. Some of the sands productive in southeastern

Ohio are the First and Second Cow Run sands, the Homewood sandstone, the Salt sands, the Keener, Big Injun, Berea and Gordon sands. In addition the Ohio shales of the Devonian system in northeastern Ohio are productive of small quantities of gas, which exist in the joint cracks.

Description of Indiana Fields.—These fields consist mainly of the northern Indiana or Trenton limestone field, of which a large portion is situated inside this State, but some gas has been produced in the Carboniferous system in southern and western Indiana and some will undoubtedly be produced there in the future. The Corniferous limestone also is productive in a small area in western Indiana, and the Oriskany sandstone and Devonian shales in southern Indiana. Twenty-seven counties were productive and 2,633 wells existed at the close of 1911. Indiana is fast decreasing in importance as a gas-producing state, owing to the decline of the gas fields. The depth of wells ranges from 130 to 1,500 feet. The structure of the northern Indiana fields consists largely of the Cincinnati anticline, and the southern Indiana fields are supposed to be due to interrupted monoclines or very gentle anticlines on the western flank of this uplift.

Description of Illinois Fields.—The Illinois gas fields are distributed widely over the State but exist in only sixteen counties, and there were only 458 wells producing at the close of 1911; the depth was from 80 to 1,680 feet. The gas has been produced mainly from the middle and lower portions of the Carboniferous system; but a small amount comes from the Niagara limestone. In the Pennsylvanian series of the Carboniferous are the Robinson and Bridgeport sands, and in the Mississippian series are the Kirkwood, Tracy, McCloskey, Stein, Benoist, Lindley and some others. The geological structure in most of the Illinois fields is anticlinal.

Description of Kansas Fields.—The gas fields of Kansas are all situated in the southeastern part of the state. At the close of 1911 there were 2,004 wells situated in twenty-one counties, the depth ranging from 80 to 1,300 feet. The gas is all derived from the lower part of the Carboniferous system and exists on monoclines

or on small anticlines or terraces. The geological structure in this State has never been deciphered in detail, except in one or two small areas.

Description of Missouri Fields.—There were only 60 gas wells in the State of Missouri at the close of 1911. The wells were shallow, ranging from 100 to 460 feet in depth and were all situated in three counties adjoining Kansas.

Description of Oklahoma Fields.—The Oklahoma fields are situated in widespread parts of the state, but the northeastern part is most productive. The fields lie in 19 counties and range in depth from 380 to 2,500 feet. The greater part of the gas in Oklahoma is derived from the Carboniferous system, but in southern Oklahoma some of it is produced from the Cretaceous. The geological structure is monoclinal, interrupted by moderate anticlines, domes and terraces.

Description of Alabama Fields.—The Alabama fields are yet in their infancy as regards development. There were only 17 gas wells in the state at the close of 1911, all of them being situated in four counties. The gas occurs in Carboniferous strata and is associated with anticlinal and terrace structure.

Description of Arkansas Fields.—Only one discovered gas field exists in Arkansas, and in it there were 110 wells at the close of 1910. At present the field is unimportant, but other fields may be developed in future. The structure of the existing field is supposed to be anticlinal.

Description of Louisiana Fields.—In Louisiana there were 114 gas wells at the close of 1911, some of them being of great volume. They are mainly situated in one county, in the Caddo field on the Sabine uplift—a broad anticline or geanticline in northwestern Louisiana. In southern Louisiana some gas exists associated with oil in the saline domes. All the gas in Louisiana comes from the Cretaceous system, or from sandy beds in the Tertiary.

Description of Texas Fields.—There were 68 gas wells in Texas at the close of 1911, situated principally in four counties, all in the extreme north or in the coastal plain of southeastern Texas. In the North Texas fields the structure is supposed to be

anticlinal or monoclinal. In southern Texas it consists of saline domes, and the gas is associated with oil. The Texas fields belong mostly in the Cretaceous system.

Description of South Dakota Gas.—Most of the gas produced in South Dakota is derived from artesian wells situated in five counties. The production is small and no data on the subject are at hand.

Description of Colorado Gas.—Only a few wells in Colorado produce gas and this comes mostly from oil wells in the Boulder and Florence fields.

Description of Wyoming Fields.—There are only 23 producing gas wells in the state and they are situated in three counties.

Description of California Fields.—In California there were only 60 gas wells in use at the close of 1911, and California is not yet a large producer of gas.

Description of North Dakota Gas Fields.—In North Dakota there are only a few gas wells which are mostly of shallow depth.

CONDITIONS NECESSARY FOR NATURAL GAS ACCUMULATION.

Wherever natural gas occurs throughout the world there are three factors which are necessary to assure its accumulation at any particular locality. These are (*a*) a porous formation to act as a reservoir; (*b*) an impervious cover to prevent the gas from escaping; and (*c*) some form of geological structure to concentrate it.

As a rule natural gas is found in sedimentary formations which are unbroken by faults and but little folded or disturbed otherwise. The fields of Ohio, Pennsylvania, West Virginia, New York, Indiana, Illinois, Kentucky, Alabama, northern Louisiana, Oklahoma and Kansas all have this peculiarity. There are some exceptions, however, and among these may be included the saline dome fields of Louisiana and some California fields in which faults exist.

GEOLOGICAL HORIZONS OF NATURAL GAS.

Natural gas occurs in rocks of all geological ages. It is the character of the individual formations that is essential to assure a reservoir. The gas rock must be porous; and it generally con-

sists of sand, sandstone, limestone or dolomite, although there are a few known instances where gas exists in shale. The presence of gas in limestone may be due to the natural porosity of the rock, to simple solution, or to chemical changes which result in the formation of dolomite. The exact point of occurrence may be controlled, therefore, not only by the structure of the rock, but also by its internal characteristics. Since its upper portions correspond with places of change from limestone to dolomite, the highest portion of the anticline is more commonly the region saturated with gas. In the case of sandstone, the occurrence of gas is due not only to structure, but is affected also by the continuity of the stratum. Not all sandstone contains gas, one essential feature being that the individual grains comprising the rock shall be rounded sufficiently to assure a porous bed which forms a reservoir. Well drillers recognize the internal variations when they speak of a sand being "open" or "close," "soft" or "hard," "good" or "poor" in character. An experienced driller can determine the porosity of a sand satisfactorily by an eye examination, but he is unable to determine whether it would be productive without knowing the geological structure of the locality in question. In order to illustrate the wide occurrence of natural gas stratigraphically, the following summary is given of the various horizons at which it is known to exist in the principal fields of the United States and Canada:

CRETACEOUS AND TERTIARY SANDS AND LIMESTONES (IN TEXAS, LOUISIANA AND CALIFORNIA).

Carboniferous System.

Permian series (in Texas and Oklahoma).
Conemaugh formation (in West Virginia, Pennsylvania and Ohio).
Allegheny formation (in Pennsylvania, West Virginia and Ohio).
Pottsville formation and its stratigraphic equivalents (in Pennsylvania, West Virginia, Ohio, Kansas, Oklahoma and Kentucky).
Mauch Chunk formation (in Ohio and West Virginia).
Pocono formation (in West Virginia, Pennsylvania, Ohio and Kentucky) and Mississippi limestone (in Oklahoma).

Devonian System.

Catskill formation (in Pennsylvania, West Virginia, Ohio, Kentucky, western New York and southern Indiana).

Chemung formation (in Pennsylvania, West Virginia, New York, Kentucky, southern Indiana and southwestern Ontario).
Corniferous limestone (in New York and Ontario, and locally elsewhere).
Oriskany formation (in Ontario).

Silurian System.

Guelph limestone (in southern Ontario and western New York).
Niagara limestone (in southern Ontario, western New York and Indiana).
Clinton formation (in central Ohio and southern Ontario).
Medina formation (in southeastern Ontario, New York and central Ohio).

Ordovician System.

Trenton limestone (in Ohio, Indiana, Kentucky, Ontario and New York).
Calciferous sandstone (in southern Ontario).

Cambrian System.

Sandstones and shales of the Potsdam sandstone and the Quebec group and their stratigraphic equivalents (in Alabama, northwestern Newfoundland and New York State).

IMPERVIOUS COVER OR CAP-ROCK OVERLYING THE OIL SAND.

Ordinarily the bed of impervious rock overlying a "sand" which holds oil or gas is known as the "cap rock." It is frequently very hard, though not always, and generally consists of limestone or shale. One of the most widespread formations to overlie gas and oil sands is the Utica shale above the Trenton limestone in the Ohio-Indiana fields. The Clinton sand of central Ohio is overlain in a similar way by the Clinton shale. The numerous oil and gas sands of Pennsylvania and West Virginia are all overlain by impervious shales. In the Louisiana fields a very hard stratum of limestone sometimes acts as a cap-rock overlying a more pervious portion of the same formation. In fact cap rocks may consist of almost any material other than sandstone.

TYPES OF GEOLOGICAL STRUCTURE NECESSARY FOR NATURAL GAS ACCUMULATION.

In order to consider the various geological structures in which natural gas is known to exist, the writer has had occasion to classify them. The original classification was published in ECONOMIC GEOLOGY[1] and it referred to accumulations of oil as well as gas. The classification is here modified to include simply the natural gas fields of the United States:

[1] F. G. Clapp, ECON. GEOL., Vol. V., No. 6, 1910, pp. 503–521.

CLASSIFICATION OF GEOLOGICAL STRUCTURES ON WHICH GAS ACCUMULATION EXIST.

I. Where anticlinal structure exists.
  (*a*) Strong anticlines standing alone.
  (*b*) Well-defined anticlines alternating with synclines.
  (*c*) Structural terraces.
  (*d*) Accumulations on monoclines due to thinning out or change in texture of the sand as it rises toward the nearest anticline.
  (*e*) Broad geanticlinal folds.
II. Quaquaversal structures.
  (*a*) Anticlinal bulges.
  (*b*) Stratigraphic domes.
  (*c*) Saline domes.
III. Contact of sedimentary and crystalline rocks.
IV. In joint cracks.
V. Where there is no particular gas structure, but the gas is associated with adjacent oil pools.

In order to explain these types of geological structure, and their bearing on the occurrence of natural gas accumulations, the various subdivisions of the classification will be briefly described with mention of the fields in which gas occurs.

Class I. Where Anticlinal Structure Exists.—This is the class of oil and gas accumulation which is most familiar. It embraces a large majority of the known fields of the world. The Appalachian, Mid-Continent, Illinois, Indiana, Oklahoma, Wyoming, Montana, Colorado, northern Louisiana, northern Texas and some of the California fields in this country, and the Russian, Austrian, Burma and Borneo fields in the eastern hemisphere, all belong to this class. It is divided into five subclasses, in order to distinguish between various structural relations in which gas is found in connection with anticlines. The anticlinal theory was promulgated by White in 1885.[1]

Subclass I. (*a*) *Gas on Strong Anticlines Standing Alone.*—In this division are included fields which bear a direct relation to

[1] I. C. White, *Science*, N. S., June 26, 1885.

pronounced uplifts which are easily recognizable and constitute a marked topographic or geologic feature of the region. One of the best known fields of this kind in eastern United States is the Eureka-Volcano-Burning Springs anticline in West Virginia, recognized by oil men at an early date, described by White, Andrews, Evans and others, and which has been thoroughly drilled. It is classified separately for the reason that its trend is very different from that of other anticlines in the region and was probably produced by a distinct force.

Several of the California and Wyoming fields which are situated on sharp anticlines belong in subclass I. (*a*). In the gas fields of Pennsylvania and West Virginia, there are a few prominent anticlines in the vicinity of the Allegheny Mountains on which natural gas is found in large quantities, and which are very distinct from other anticlines of the region in their topography, and the fields situated on such anticlines should probably be considered in this subdivision. The most important of these major folds is the Chestnut Ridge anticline, which is productive at several points in West Virginia but not in Pennsylvania. Fig. 43 illustrates the occurrence of a gas field on a typical anticline.

Subclass I. (*b*) *Gas on Well-defined Anticlines Alternating with Synclines.*—Although this might be considered a composite of subclass I. (*a*), it is discussed separately for the reason that in regions of slight folding the anticlines and synclines are frequently much confused and their status is consequently somewhat doubtful. This subclass includes the entire Appalachian fields in Pennsylvania, West Virginia and eastern Kentucky, many of the Illinois and Oklahoma fields, possibly the north Texas fields and those of Colorado, Wyoming and Montana. Several of the gas fields of California, among which are the Coalinga and the Los Angeles fields,[1] also belong to this class. A great many of the foreign oil fields belong in subclass I. (*b*), but they are too numerous to be considered in a brief discussion.

[1] George H. Eldridge, Bulletin 213, U. S. Geol. Survey, 1903, pp. 306–321; Ralph Arnold and Robert Anderson, Bulletin 357, U. S. Geol. Survey, 1908, pp. 70–71.

In Armstrong and Butler Counties and some of the adjacent counties in Pennsylvania, natural gas is of very widespread

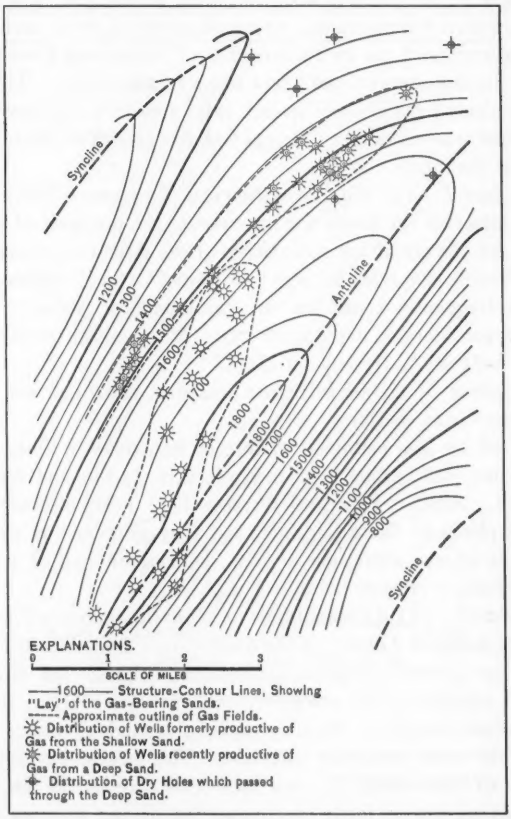


FIG. 43. Typical occurrence of natural gas fields on anticlines in Pennsylvania and West Virginia.

occurrence, frequently being found in the synclines as well as on the anticlines and in many cases apparently not related to the

structure. The discrepancy may be explained by the statement that all of the formations in that particular district are at a high elevation in comparison with the same formations in extreme southwestern Pennsylvania, where oil exists in them, and hence the occurrence of gas in the synclines of Armstrong County is a step in its ascendency from lower levels farther south. The local distribution of gas deposits in such cases appears to be determined by minor interruptions or changes in dip or difference in character of the sand.

Subclass I. (*c*) *Gas on Structural Terraces.*—While I. C. White deserves the credit for discovering the presence of gas on anticlines, the credit for recognition of the structural terrace and its favorable character belongs to Edward Orton. Although oil also is frequently found on structural terraces, some of them contain considerable deposits of gas. A structural terrace is in reality only an "arrested anticline."

The effect of terrace structure was first explained and illustrated by Orton in 1886.[1]

One of the best examples of terrace structures in Ohio is the Macksburg field, which was recognized by Orton and Newhall in 1888. Similar structural terraces have been discovered in several places in West Virginia, and they undoubtedly exist in all states where natural gas occurs. A contour map of a structural-terrace is represented in Fig. 44.

Subclass I. (*d*) *Accumulations on Monoclines Due to Thinning Out or Change in Texture of the Sand.*—In a monocline the rocks dip in one general direction throughout, although the dip may vary in steepness from place to place. In this subclass the accumulations are due to thinning out of the sand or change in its texture in some particular direction. The largest gas fields in regions of monoclinal dip owe their existence to the fact that all sands are not perfectly continuous but die out in some direction. Several of the Kansas and Oklahoma fields are of this type, and it appears to prevail to some extent in the Caddo fields of Louisiana; but the most notable occurrence is in the Clinton

[1] Edward Orton, *Science*, Vol. 7, p. 563.

sand of central Ohio. As shown by the diagram (Fig. 42), this sand rises from beneath thousands of feet of sediments in the Appalachian basin, grows somewhat thinner toward the Cin-

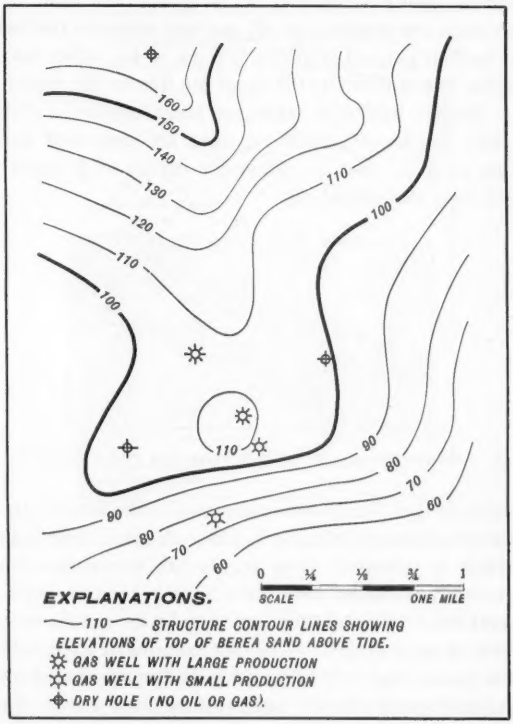


FIG. 44. Occurrence of natural gas on a structural-terrace in Ohio.

cinnati anticline, and in central Ohio, where it approaches nearest the surface, it dies out. It is on this thinning edge that the great Central Ohio gas belt is found, having a breadth of from five to fifteen miles.

While the texture or dying out of a sand is not responsible as a

rule for the exact positions and limits of the oil pools on monoclinal dips, there are exceptions to this statement. In the Louisiana fields some of the oil and gas accumulations are contained in lenticular sands which thin out or grade into shale laterally. In such cases the relations of oil, gas and water in the sands are similar to their general relations to those in any other monocline, except that the outlines of the pools are due to the extent of the sands. Similar lenticular sands are abundant in the California fields, and similar structural relations are described and illustrated by Arnold. Fig. 45 shows the details of a typical dying out sand on a monoclinal dip.

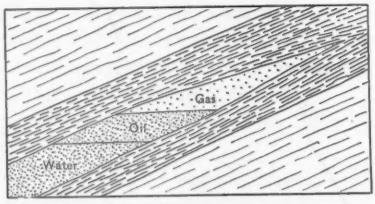


FIG. 45. Arrangement of gas, oil and water in a typical lenticular sand.

Subclass I. (*e*) *Gas Fields on Broad Geanticlinal Folds.*—This is an extreme type of subclass I. (*a*). A geanticline is an anticline which is extremely long and broad, sometimes extending over a breadth of one hundred miles or more, and having a length of several hundred miles; its area may be thousands or tens of thousands of square miles. The best example of a gas field existing on a geanticlinal fold is the Ohio-Indiana field which lies on the Cincinnati geanticline in northwestern Ohio and northeastern Indiana. This is illustrated by the west end of the section in Fig. 42. Another example of a field belonging in this classification is the Caddo field of northwestern Louisiana. In these two fields the general presence of oil and gas is determined by the existence of the main fold, but the details may be due to structural terraces or minor warpings.

Class II. Quaquaversal Structures.—A quaquaversal struc-

ture is one in which the strata dip down and outward from a central point. There are various types of quaquaversal structure, but only two are known to produce gas in the United States.

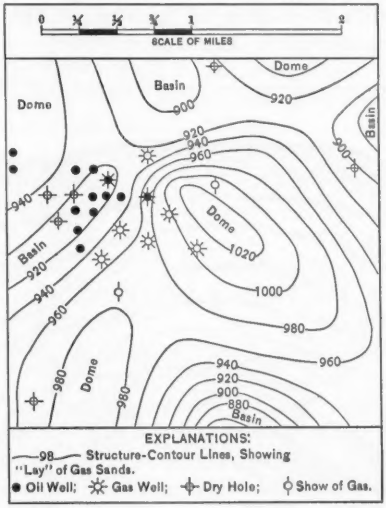


FIG. 46. Typical occurrence of gas on a structural dome in Oklahoma.

Subclass II. (*a*) *Gas Fields on Anticlinal Bulges.* It has been proved that not all portions of an anticline which are underlain by pervious sand are productive of gas, but gas occurs only at certain favored regions where the structure is suitable. One type of region where natural gas may be expected is where a dome, knob or bulge in the crest of the anticline forms a suitable pocket for accumulation. Such domes in anticlines exist at many localities in Pennsylvania, West Virginia and Oklahoma. They consist of more dome-like modifications of Fig. 43.

Subclass II. (*b*) *Gas in Stratigraphic Domes.*—In many localities in Oklahoma and other states the strata are arched into domes which have apparently no connection with an anticline; but

are irregularly distributed through the oil fields. For want of a better designation, since these structures are frequently typical domes, they are called stratigraphic domes, as distinguishing them from salines domes, which are due to a different cause from ordinary structural warping of the strata. Fig. 46 shows a typical structural dome in Oklahoma.

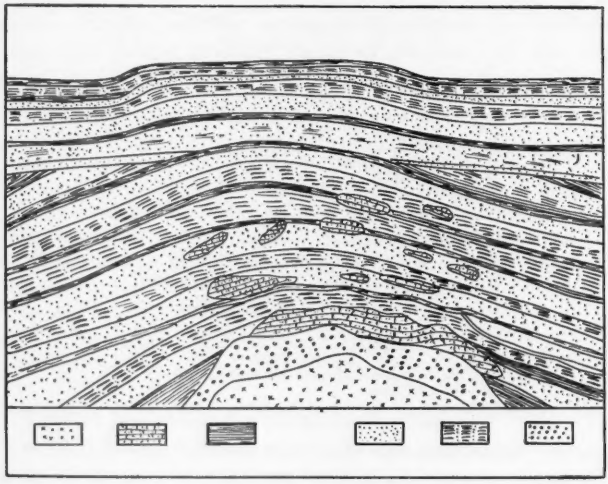


FIG. 47. Cross-section of Spindle Top oil field, Texas (after Hager).

Subclass III. (*c*) *Gas in Saline Domes.*—The saline dome type of quaquaversal structure is found, so far as known, only in one part of the United States: the Gulf Coastal plain of Louisiana and Texas. In these domes large deposits of salt and sulphur are found and in them some of the most productive oil fields of Louisiana and Texas exist. Fig. 47 is a cross-section of the Spindle Top field, Texas. Natural gas is not known to be produced commercially from these fields, but it occurs associated with the oil. Other types of quaquaversal structure exist in Mexico.

Class III. Natural Gas at the Contact between Sedimentary and Crystalline Rocks.—The principal examples of this class are in the Province of Qubec and in northern Ontario. It is possible that gas also may occur in this manner at some places in New York State. The gas is held in the zone of the arkose Potsdam sandstone which rests directly upon prominent knobs of the granite under the finer-grained sandstone cappings.

Class IV. Gas in Joint Cracks.—The occurrence of natural gas in joint cracks is not common, but there is a considerable area extending along the south shore of Lake Erie from central Ohio eastward into New York State where small deposits of natural gas exist in this manner in the Ohio shales, and are utilized to some extent.

Class V. Where no Particular Gas Structure Exists, but the Gas is Given Off from an Adjacent Oil Pool.—A number of small gas fields, or, more properly "pockets of gas" have been discovered in Ohio, West Virginia, Oklahoma and other fields where the gas does not seem to owe its presence to any of the forms of structure listed above; but in such cases the gas has always been found to exist in close proximity to an oil field on its up-dip side. These deposits of gas are of small area and are generally separated from larger gas fields by dry areas. Such gas has risen off the oil. It accumulates in proximity to the oil for the reason that it contains vapors of gasoline and is therefore heavier than air. This type of gas field is utilized in part for extracting natural gas gasoline.

Apparent Discrepancies Due to Convergence of Strata.—One of the mistakes of the earlier geologists and gas engineers was the assumption that surface formations are universally parallel with the oil sands. This is true in many fields, but in others it is far from being so. For example, the Clinton sand in Ohio is not even approximately parallel with any surface formation; but the interval between the Clinton and the surface strata increases toward the east at an average rate of forty feet per mile, thus bringing the Clinton rapidly to a great depth, as shown in Fig. 42. Nearly every formation thickens greatly from Indiana

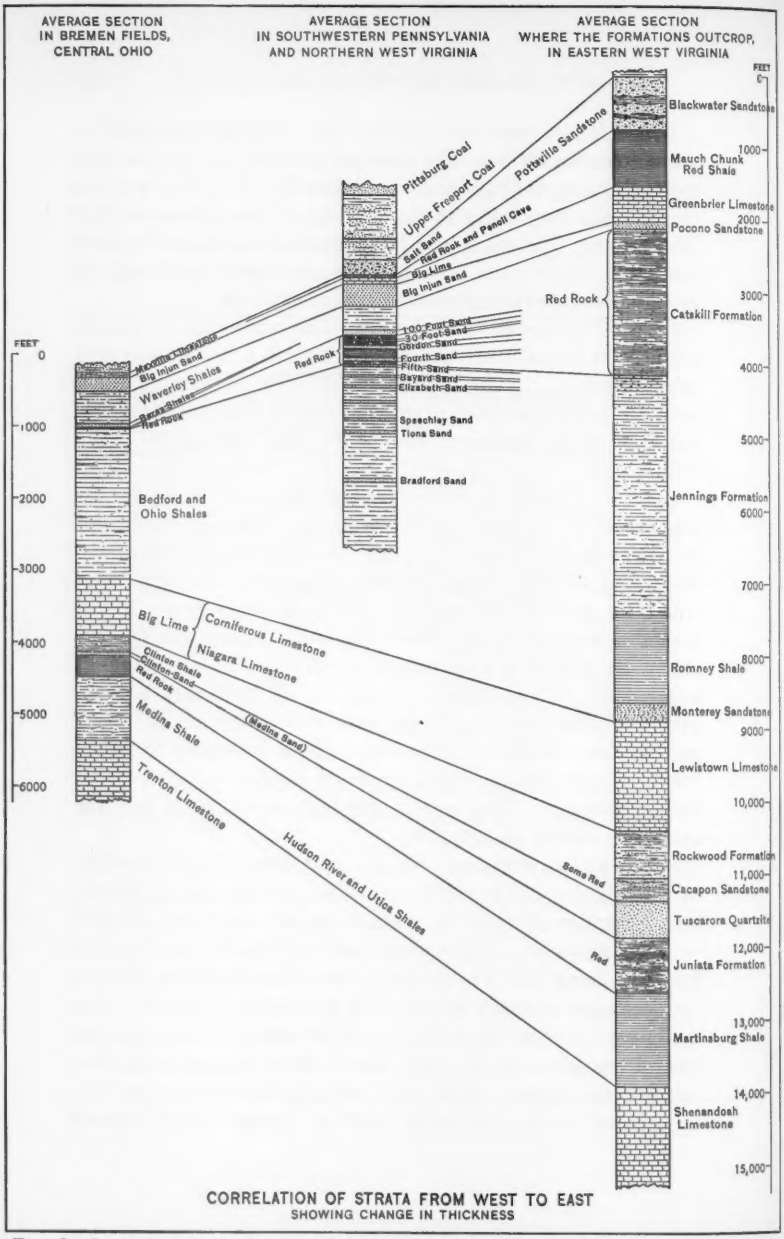
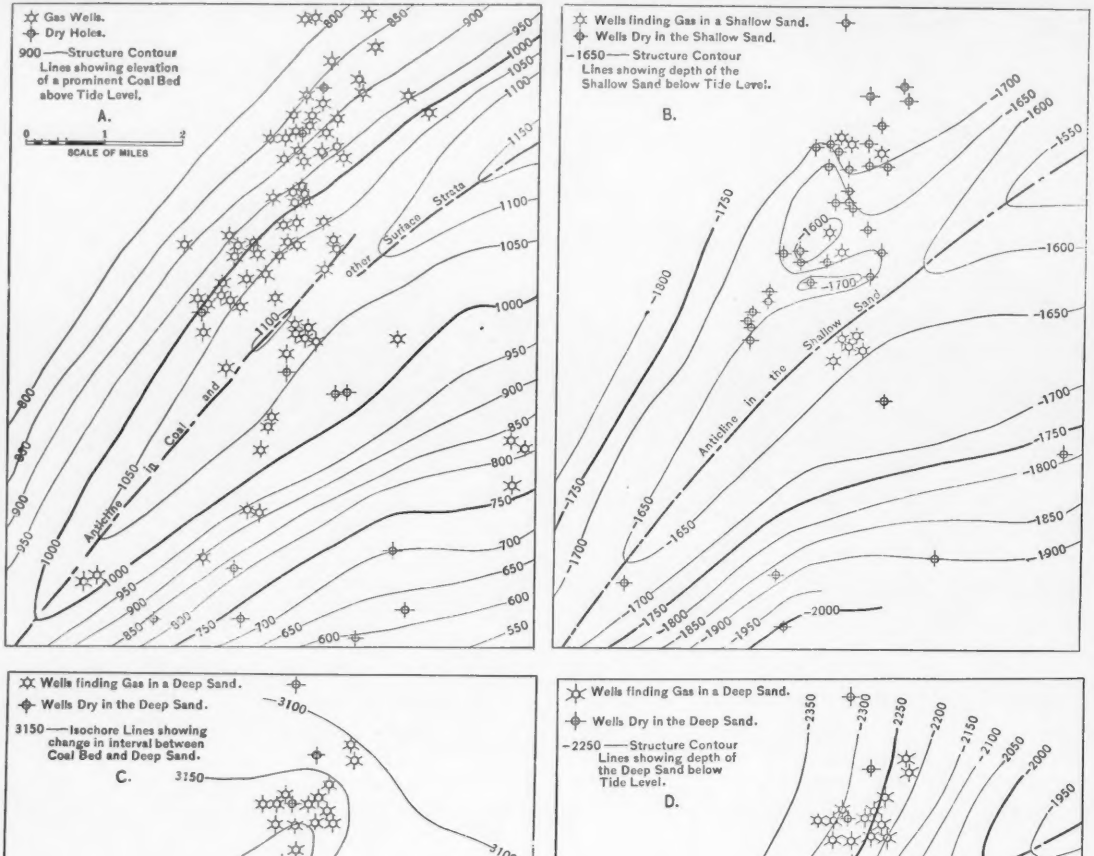


FIG. 48. Correlation of natural gas sands in Central Ohio fields with formations outcropping in Allegheny Mountains, showing increase in intervals eastward.


Gas Wells.
Dry Holes.
900—Structure Contour Lines showing elevation of a prominent Coal Bed above Tide Level.
A.
SCALE OF MILES
Anticline in Coal sand
other Surface Strata
Wells finding Gas in a Shallow Sand.
Wells Dry in the Shallow Sand.
-1650—Structure Contour Lines showing depth of the Shallow Sand below Tide Level.
B.
Anticline in the Shallow Sand
Wells finding Gas in a Deep Sand.
Wells Dry in the Deep Sand.
3150—Isochore Lines showing change in interval between Coal Bed and Deep Sand.
C.
Wells finding Gas in a Deep Sand.
Wells Dry in the Deep Sand.
-2250—Structure Contour Lines showing depth of the Deep Sand below Tide Level.
D.

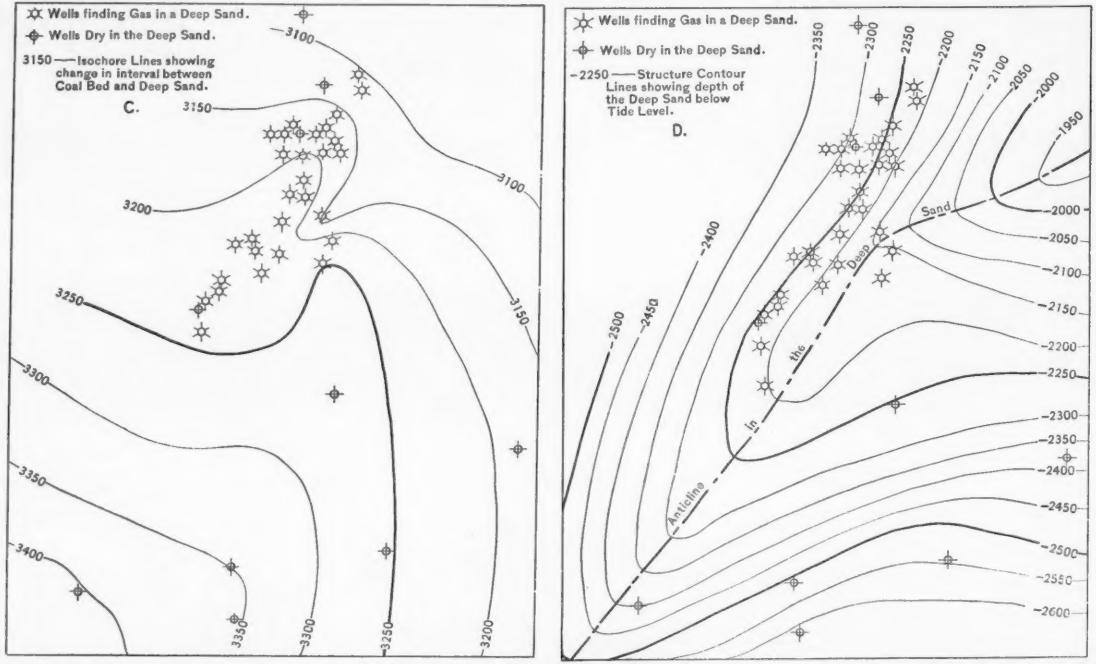


Plate X. Illustration of an anticlinal gas field in Pennsylvania in which several sands are productive. A shows lay and dip of surface strata, with positions of all wells; B shows lay and dip of a shallow sand, with positions of wells drilled to it; C is a convergence map used in calculating the lay of the deep sand for Pl X-D; D shows lay and dip of a deep sand, with positions of wells drilled to it.

eastward to the Allegheny Mountains, so that the section which is about 6,000 feet thick in the Central Ohio gas field increases to about 15,000 feet in central Pennsylvania and eastern West Virginia. This change is illustrated by Fig. 47. It will be noted that several of the great productive formations have never been reached by the drill in Pennsylvania and West Virginia.

With the assistance of a few well records which penetrate a particular sand within and near any locality where development has been commenced or testing done, it is possible to determine the structure and "lay" of this sand with a fair degree of accuracy. This is done by first making a contoured structural map of some surface formation; then the exact intervals from this bed to the particular sand are found in whatever wells have been drilled to the sand in the vicinity, and a convergence map is prepared on the same scale.

In preparing a structure map of a gas sand which is approximately parallel to the surface formations, a convergence sheet must be prepared showing the intervals from some particular surface stratum down to the top of the sand. By subtracting these figures from the figures on the map which show the "lay" of the surface formations, the geological structure of the particular sand is calculated. A large number of oil and gas fields in Pennsylvania, Ohio and Oklahoma, which do not seem to have any particular structural relations, are due to the fact that the anticlines in the underlying formations do not lie exactly underneath those in the surface formations. This condition is illustrated to a certain extent by Plate X., which shows four separate maps of a prominent Pennsylvania anticline, in which several sands are productive. The important point to emphasize is that the agreement between the geological structure and position of the gas field may not be evident from the surface structure, on account of the convergence illustrated in Figs. 42 and 48; but when the local extent of the non-parallelism and the structure of the individual sands has once been determined, the gas is found to correspond with the structure. In the case of Fig. 43, if the intervals and structure of the deep sand were deciphered, the

gas field in this sand would be found to agree closely with the crest of its anticline.

ORIGIN OF NATURAL GAS.

The theories to explain the origin of oil and gas are very numerous, but they may all be classified according either to the organic or the inorganic group of theories. Among the former, the volcanic theory was first stated by Humboldt in 1804, but it was first put in definite shape by Berthelot. Another inorganic theory was propounded by Maquenne[1] in 1892. Other advocates of inorganic theories of one kind or another were Travers in 1893; Wilson[2] in 1895; Mathews[3] in 1899; Byerson[4] in 1871; Cloez[5] in 1878; Mendeleff[6] in 1879; Ross[7] in 1891 and Sokoloff in 1890. The general substance of these various hypotheses seems to be that surface water has penetrated downward through fissures in the rocks and has acted chemically on carbide of iron under high temperature in the earth's interior, producing petroleum and natural gas. The argument for the inorganic origin has been ably summarized by Costé.[8]

The various organic theories are in brief that petroleum and gas have originated by the decomposition of organic matter buried in the rocks. Organic theories have been advocated by Hunt, Leslie, White, Whitney, Orton, Wall, Peckham, Newberry, Phillips and Höfer. The upholders of the organic theory differ among themselves as to whether oil and gas originated (*a*) *in situ* or (*b*) by distillation from other formations, and as to whether the substances have come (*c*) from vegetable matter or (*d*) from animal matter. The most prominent believers in the animal hypothesis have been Höfer,[9] Newberry,[10] Hunt, Von

[1] *Comptes Rendus*, Vol. 114, p. 677.
[2] *Jour. Soc. Chem. Ind.*, Vol. 14, p. 145.
[3] *Jour. Am. Chem. Soc.*
[4] *Comptes Rendus*, Vol. 73, p. 609.
[5] *Loc. cit.*, Vol. 75, p. 1003.
[6] *Jour. Russk. Ph.-Kh. Obsch*, Vol. 9 (1), p. 36; *Jour. Chem. Soc.*, Vol. 36, p. 283.
[7] Rep. Brit. Assoc., p. 639.
[8] *Jour. Can. Min. Inst.*, Vol. 12, 1909.
[9] *Proc. Manchester Lit. Phil. Soc.*, Vol. 3, p. 136; "Das Erdol," p. 118.
[10] Geol. Survey Ohio, 1878, Pf. I., pp. 125 and 174.

Buch, Bertals, Zinchen, Zaloziecki[1] and Engler.[2] The principal believers in the vegetable hypothesis have been Lesquereux, Phillips, Witt, Kramer and Spilker.[3] Peckham and Orton believed that some petroleums are of animal and some of vegetable origin. The names of the recent American theorists are not given, for the reason that time has not been available to definitely learn the various views.

It seems probable that the Höfer-Engler view has the greatest number of adherents at the present time. These authors believe that oil and gas are due to distillation from animal remains in adjacent or underlying formations. While the present writer is not an authority on the chemistry of this subject and his views may consequently not be given much weight, he believes, judging from the many grades of petroleum found in numerous geological situations in different parts of the world and with different chemical composition, that oil and gas have been formed in more ways than one. There seems no necessity for believing that the heavy viscous fuel oil of Mexico, with a gravity sometimes as low as 9 degrees Baume, is similar in origin to the light refining oil of Pennsylvania and West Virginia, which has a gravity of 45 to 50 degrees and which is very different in appearance and characteristics.

Anticlinal Theory.—In considering the geological structure of gas fields, much has been heard in the past about the "anticlinal theory." This theory still has its advocates and its opponents. It has been of great value in locating natural gas fields, but gas is also subject in its occurrence to other factors which account for the apparent failure of the theory in some localities. Moreover, gas occurs in other types of geological structure, as is explained in paragraphs 25 to 37; and a knowledge of all these types is necessary to a geological engineer in making predictions of value.

The theory has been investigated and advanced to a certain

[1] *Dingler's Polytech. Jour.*, Vol. 280, pp. 69, 85 and 133; *Chemiker Zeitung*, Vol. 15, p. 1203.

[2] Redwood's "Petroleum and its Products," 1906, pp. 259–261.

[3] *Op. cit.*

extent by T. Sterry Hunt,[1] E. Benjamin Andrews,[2] J. J. Stevenson,[3] Minshall[4] and others. The theory was not definitely formulated, however, until 1885, when I. C. White[5] worked out its details and applied the theory practically, locating oil and gas fields in West Virginia and Pennsylvania by means of it. White's theory was applied strictly to saturated rocks. In dry rocks somewhat different conditions exist, and in such instances the theory is modified. Edward Orton[6] deserves great credit for deciphering the geological structure of structural terraces along parallel lines of research. The various theories for the accumulation of gas have been ably summarized by Campbell.[7]

[1] *Can. Nat.*, Vol. 6, pp. 241–255, August, 1861; Can. Geol. Survey, 17th Rept. of Progress, 1863–66, p. 233.

[2] *Am. Jour. Sci.*, 2d Ser., Vol. 32, pp. 85–93, 1861.

[3] Sec. Geol. Survey of Pa., Vol. *H*, pp. 394–5, 1875.

[4] In letters to the *State Journal* of Parkersburg, West Virginia, in 1861.

[5] *Sci.*, Vol. 6, June 26, 1885; *Bull. Geol. Soc. Am.*, Vol. 3, 1892, pp. 187–216; W. Va. Geol. Survey, Vol. 1–A, 1904, pp. 48–64.

[6] Geol. Survey Ohio, 1886, Vol. 6, pp. 21 and 94.

[7] M. R. Campbell, ECON. GEOL., Vol. 6, No. 4, 1911, pp. 363–386.

ARTIFICIAL VEIN-FORMATION IN THE TOMBOY MILL, TELLURIDE, COLORADO.

J. F. Kemp.

In the summer of 1912, while remodeling the concentrate-dryer of the Tomboy mill, Telluride, Col., Mr. Gelasio Caetani discovered the steam-pipes of the radiator to be covered with a solid incrustation. For somewhat longer than two years the steam-pipes had been buried beneath a layer of concentrate, three inches thick. As the pipes were only used for heating and drying moderate steam-pressures were employed, which would involve relatively low temperatures. The altitude of the mill is 11,450 feet above the sea-level, and in consequence the temperature of the pipes could hardly have averaged above 200–250° Fahrenheit or 93–120° Centigrade. Under the action of these comparatively low temperatures and in the presence of the moisture, the fine particles became cemented together to a firm mass which peeled off in cakes, three quarters of an inch (20 mm.) thick. Two pieces were very kindly sent to the writer by Mr. Caetani in September, 1912, and from them a series of nine thin sections were prepared in various positions. Subsequently in March, 1913, Mr. J. W. Finch supplied a third and smaller piece which was collected by Mr. William Lay. Mr. Caetani has also very kindly furnished the necessary data for tracing the history of the specimens and has suggested their interest for study and record. To all these gentlemen, but especially to Mr. Caetani, the writer's thanks are due. The specimens are of unusual interest in that we practically have the results of vein formation which took place at low temperatures and in a comparatively brief space of time.

The mineralogy of the Tomboy lode has been carefully studied and recorded by C. W. Purington and F. L. Ransome.[1] Its chief

[1] C. W. Purington, Telluride Folio, U. S. Geol. Surv. and 18th Ann. Rept. U. S. Geol. Survey, 3, 782, 1898. The Tomboy is in the Savage Basin just over

gangue is quartz and much the greater part of the value is in gold (nineteen-twentieths when Mr. Ransome visited the mine). The metallic minerals are pyrite, galena, chalcopyrite, and zinc-blende, with some soft black peroxide of manganese in the vein. The metallic minerals are a relatively small part of the vein-filling. The principal part is quartz, with which is finely divided gold. There is some calcite, fluorite and probably siderite. Sericite and the clay-like products of decomposition are not to be overlooked. Very little of these light, scaly minerals, however, are to be expected in the concentrate, whose chief components must be quartz and the sulphides.

Mr. Caetani has furnished the following approximate composition of the concentrate:

Zinc	22
Iron	20
Lead	6
Copper	4.5
Insoluble	9
Total	61.5

	Oz.
Gold	6
Silver	6.9
Quicksilver from the plates.	

Under the microscope it is possible to recognize among the metallic minerals (including zincblende with them) pyrite and zinc-blende as the most abundant ones. Chalcopyrite and galena are less abundant. The chalcopyrite appears intimately intergrown with the pyrite. There are one or two fragments of a reddish-brown translucent mineral of high refractive index of whose identity the writer is not certain. An occasional gray metallic grain shows a purplish cast like bornite, but all these exceptional cases are small and practically negligible components. A sliver of clear and unchanged quartz is once in a while sharp and distinct. With low powers (three quarter inch objective) the matrix in which the metallic grains are set is cloudy and while obviously crystalline the components require higher powers for their resolution.

the eastern boundary of the Telluride quadrangle in the Silverton. Details of the lode are also discussed by F. L. Ransome in his bulletin on the "Economic Geology of the Silverton Quadrangle," U. S. Geol. Survey Bulletin, 182: 206–211, 1901, and in the Silverton Folio, 1905.

If we recast the above analysis on the basis of the observed mineralogy we obtain the following percentage compositions both by weight and by volume. All the copper has been first assigned to chalcopyrite which is assumed to be the theoretical 34.6 per cent. copper. About four of the per cents of iron go with the copper into the chalcopyrite. The remaining sixteen are assigned to pyrite. The metallic zinc is practically two thirds the total zinc-blende. All the lead is assigned to the galena. The precious metals are too small to appear and other metallic minerals, if present, must form very small proportions of the total. That all the insoluble portion was quartz may be questioned, but by far the greater part of it undoubtedly was. There might have been a little fluorite and insoluble residue of wall rock. The 3.7 per cent. unaccounted are probably soluble gangue minerals—calcite, siderite, etc.—with perhaps some water. As earlier remarked, the light scaly sericite and kaolinite must have almost or quite all have floated off in concentration.

	Per Cent. by Weight.	Per Cent. by Volume.
Pyrite	34.3 ÷ 5.0	= 6.9 or 29.0
Zincblende	33.0 ÷ 4.0	= 8.2 or 34.4
Chalcopyrite	13.0 ÷ 4.2	= 3.0 or 12.6
Galena	7.0 ÷ 7.5	= 1.0 or 4.2
Quartz	9.0 ÷ 2.65	= 3.4 or 14.3
Total	96.3	
Silver, gold, etc.	3.7 ÷ 2.75	= 1.3 or 5.5
Grand total	100	23.8 or 100.0

From the above percentages by volume it would appear that the gangue minerals were roughly about 20 per cent. of the total volume; the ore minerals 80 per cent. In the slides one gains the impression that there is relatively more of the gangue. If we add the chalcopyrite to the pyrite, making a total of 41.6, the figures correspond very closely to the impressions for these minerals received from the slides.

The size of the ore particles varies from a rare maximum of about one sixteenth of an inch (1.5 mm.) in longest dimension down to .002 in (.04 mm.). The general run lie between .02 and

.01 in. (.5–.25 mm.). The surviving and unchanged quartz is of the last-mentioned sizes. It is not common. The recrystallization has been thorough.

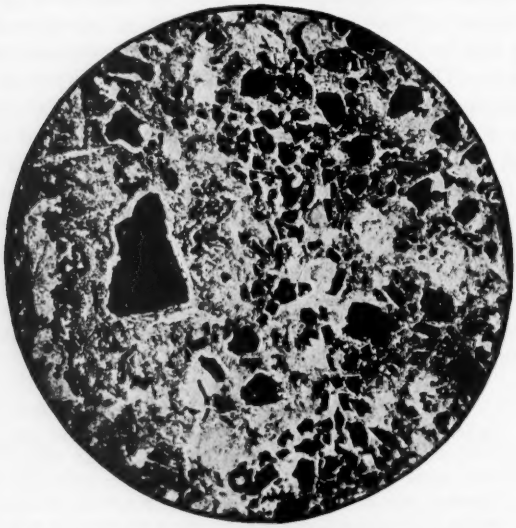


FIG. 49. Cemented concentrate, about .4 in. or 10 mm. from steam-pipe. The dark minerals are the sulphides; the light areas are recemented silica. The bright bands around the sulphides are natural; the negative has not been retouched. Actual field ⅛ in. or 3 mm. White light.

When the concentrate was placed around the steam-pipes we can but infer that the mixture of ore and gangue was uniform. In the cake, however, there is a layer next the pipe up to a quarter of an inch (6 mm.) in thickness in which there are almost no metallic particles. The occasional particle of pyrites in this area has a rim of limonite, and there is a very constant band of limonite parallel with the surface of the pipes and not quite the full width of the siliceous layer from the pipe itself. Apparently the silica, presumably in the hydrated form, has moved toward the pipes and has displaced the particles of ore, which have

become segregated farther out. They have themselves become tightly cemented together by reorganization of the silica, so that now they are set in a firm cement. So firm is the bond that thin sections can be easily ground of what was once a loose, sandy aggregate. Special interest attaches to the exact mineralogical character of the newly deposited siliceous layer.

FIG. 49*a*. Cemented concentrate, practically devoid of metallic minerals. The steam-pipe was on the left side. The banding on the right is accentuated by limonite. Actual field ⅛ in. or 3 mm. White light.

Under the microscope and without polarized light the matrix appears as a transparent mass with cloudy streaks, resembling strongly sections of chert and flint. The fragmental character has disappeared and what was once a mass of bits of quartz has become a solid aggregate. Such fragmental quartz as has survived is in the parts of the crust remote from the pipe and in the midst of the bits of sulphides. With polarized light the mass is resolved for the most part into extremely small brightly polariz-

ing points and rods. Far the greater number are undoubtedly quartz. They form nests of small radiating crystals, exactly as we see them on a larger scale associated with agate. Their cut ends give minute mosaics. There are occasional bundles of fine, brightly polarizing needles or fibers in close aggregates. They are with little doubt chalcedony. There are suggestions of

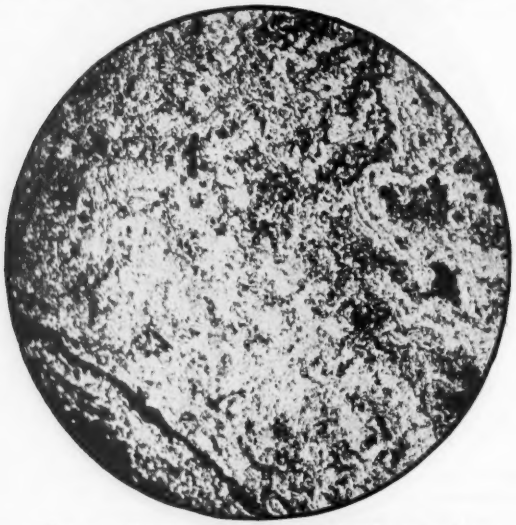


FIG. 50. The same as Fig. 49*a*, but in polarized light.

former fragmental textures now largely obliterated, as if the silica had passed through a gelatinous or semi-gelatinous stage and had recrystallized chiefly as quartz but with some chalcedony. There are some rectangular rods, with cross cleavages. They are brightly polarizing with parallel extinction. They may be calamine. They have been observed as fringes around particles of blende. All the crystals are extremely small, .001–.002 of an inch, or, say, .02–.05 mm.

The solidified mass of concentrate imitating as it does so clearly a banded vein appears to have been produced as follows: Silica,

probably in the gelatinous state has formed next the steam-pipes and has crowded back the metallic particles so as to create a band quite free from them, and up to a quarter of an inch across (3–6 mm.). In the process some of the pyrite has been oxidized and hydrated, so as to change to limonite. At the same time some sulphuric acid must have been set free, and it may have exercised some influence in the final result. We can detect pyrite grains with limonite rims still surviving. The limonite has, however,

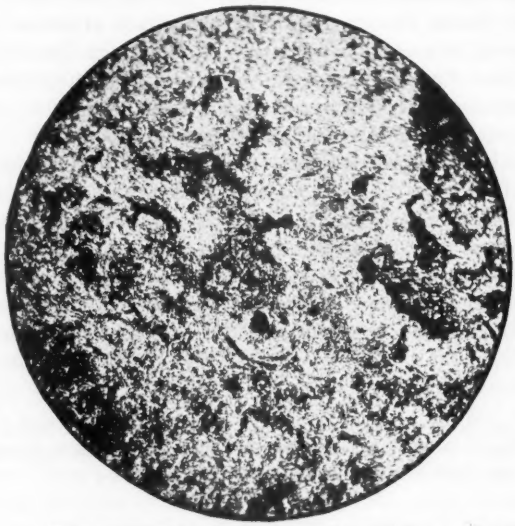


FIG. 51. The recemented silica near the steam-pipe in polarized light. Actual field 1/16 in. or 1.5 mm. The larger magnification accentuates the finely crystalline character.

been almost entirely segregated in a narrow wavy band within the siliceous layer but nearer the metallic particles than the steam-pipes. This relationship is very much the same as that obtained by artificially producing metallic precipitates in gelatinous substances. Substances of gelatinous character, more especially silica, and collectively known as "gels" are now the objects of

serious experimentation and investigation in connection with ore deposition.[1]

A beautifully colored plate in the paper just cited reminds one strongly of the crusts and of the relations of the limonite. A still earlier observer, R. E. Liesegang, as quoted in the paper, suggested the banding of agates as due to these phenomena and reproduced concentric rings by reprecipitating silver bichromate from nitrate solution dropped on gelatine. A number of similar and even more striking cases are cited by Hatschek and Simon. Apparently in the Tomboy case the ferric hydrate, as formed in the gel, spread into a narrow band rudely parallel with the surface of the pipes. Possibly some of it came from the iron of the pipes since we sometimes note a scale of iron oxide on the inner surface of the cakes and apparently derived from the pipes.

Within the distance of three quarters of an inch (20 mm.) the heat of the pipes seems to have been effective in producing the gelatinous or other solutions of the silica, but beyond this sphere of influence the concentrate remained loose and the crusts failed to form. Within this outer zone the particles of sulphides are, however, cemented to a solid mass by the silica but there has been no zonal or parallel development of bands. The working over of the silica is the only visible change. The metallic sulphides have not been visibly affected.

[1] See for instance, a valuable paper by E. Hatschek and A. L. Simon, "Gels in Relation to Ore Deposition." (Read before the Institution of Mining and Metallurgy, April 18, 1912, London.)

THE QUANTITATIVE MINERALOGICAL CLASSIFICATION OF GRADATIONAL ROCKS.

FRANCIS CHURCH LINCOLN.

INTRODUCTION.

Most of the published descriptions of rocks contain only general statements as to the quantities of minerals present. In the case of sedimentary rocks it is customary to make no detailed quantitative investigations whatever. Igneous rocks usually fare better, in that a chemical analysis is commonly made and the position of the rock in the quantitative chemical classification determined, but even with igneous rocks determinations of the quantities of minerals actually present are omitted in the majority of cases. From the theoretical point of view, a determination of the chemical constitution of an igneous rock is most desirable, but a determination of the mineral composition would seem to be of at least equal importance; while from the practical point of view —when the rock is to be used as a building or ornamental stone— it is certainly of greater value.

The common omission of quantitative mineral constitutions from rock descriptions is due in large part to the fact that the mineralogical classification of rocks is mainly qualitative in character. Even when quantitative mineral determinations are made, they do not serve to fix the name of the rock, since the names in use are without definite quantitative meanings. The result of this indefiniteness is a confused nomenclature which hampers study and retards research. The object of this paper is to present logical quantitative mineralogical classifications of gradational rocks.

I. THREEFOLD DIVISION BASED ON TWO COMPONENTS.

There is a quantitative factor in use for the classification of certain igneous rocks which is due to Brögger as interpreted by

Lindgren and modified by Hatch. Brögger[1] established the monzonites intermediate between the syenites and the diorites, and the quartz-monzonites intermediate between the granites and the quartz-diorites.

Lindgren[2] pointed out that it would be incorrect to define a series of rocks as containing approximately equal amounts of orthoclase and plagioclase and then include in it rocks having three or four times as much of one as of the other. He suggested that in the case of the quartz-bearing group, with an assumed total of 60 per cent. feldspars, those rocks containing from 60 per cent. to 40 per cent. orthoclase should be classed as granites, those with from 40 per cent. to 20 per cent. as quartz-monzonites, and those with from 20 per cent. to 8 per cent. as granodiorites. The last division is inconsistent, a place having been reserved for the tonalites with from 8 per cent. to 0 per cent. orthoclase, when they should logically be included with the granodiorites, or *vice versa*, giving a final division of rocks with from 20 per cent. to 0 per cent. of orthoclase.

With this revision, Lindgren's suggestion was adotped by Hatch.[3] He classified rocks with less than one third of the feldspar orthoclase as granodiorites, rocks with from one third to two thirds of the feldspar orthoclase as adamellites (quartz-monzonites), and rocks with more than two thirds of the feldspar, orthoclase, as granites. The diorites, monzonites, and syenites he divided in a similar manner.

This method of making threefold divisions based on the relative quantities of two groups of components which has proved useful in these few cases may profitably be extended to igneous rocks in general and to sedimentary and metamorphic rocks as well.

II. APPLICATION TO THE MINERALOGICAL CLASSIFICATION OF IGNEOUS ROCKS.

The minerals in igneous rocks may be divided into leucocratic,

[1] "Die Triadische Eruptionsfolge bei Predazzo," *Vidensk. Skrifter I. Math.-natur. Klasse* (1895), 21.

[2] *Am. Jour. of Sci.*, IV., 9 (1900), 279.

[3] "Text-Book of Petrology," London (1910), 169.

or light-colored, and melanocratic, or dark-colored. In the first division are included the minerals of the quartz, feldspar, and feldspathoid groups; and in the second those of the ferromagnesian silicate and ore groups—without reference to whether they are dark- or light-colored. Brögger has defined leucocratic rocks as those in which leucocratic minerals predominate, melanocratic rocks as those in which melanocratic minerals preponderate, and mesocratic rocks as those in which leucocratic and melanocratic minerals are about equally abundant. By making his definitions quantitative and volumetric the following divisions are obtained.

TABLE I.

ROCK DIVISIONS.

Division.	Per Cent. Leucocratic Minerals by Volume.	Per Cent. Melanocratic Minerals by Volume.
A. Leucocratic	67–100	33–0
B. Mesocratic	33–67	67–33
C. Melanocratic	0–33	100–67

These divisions may be subjected to threefold subdivision based on groups of light-colored minerals present in rocks belonging to the first two divisions and on groups of dark-colored minerals present in rocks belonging to the last. Such a classification is shown below.

TABLE II.

ROCK GROUPS.

Division.	Group.	Percentage Leucocratic Minerals by Volume, which is:			Percentage Melanocratic Minerals by Volume, which is:	
		Quartz.	Feldspar.	Feldspathoid.	Ferromagnesian Silicate.	Ore.
A	(*a*) Quartz	100–67	0–33			
	(*b*) Quartz-feldspar	67–33	33–67			
	(*c*) Feldspar	33–0	67–100	33–0		
	(*d*) Feldspar-feldspathoid		33–67	67–33		
	(*e*) Feldspathoid		0–33	100–67		
B	(*f*) Feldspar	33–0	67–100	33–0		
	(*g*) Feldspar-feldspathoid		33–67	67–33		
	(*h*) Feldspathoid		0–33	100–67		
C	(*i*) Ferromagnesian silicate				100–67	0–33
	(*j*) Ferromagnesian silicate-ore				67–33	33–67
	(*k*) Ore				33–0	67–100

The quartz group of rocks does not require further division since there are only two minerals in the quartz group—quartz and tridymite—and the latter is rare. All the other groups may be divided into series according to percentages of mineral subgroups present. Thus the quartz-feldspar and feldspar groups of the leucocratic division and the feldspar group of the mesocratic division may be divided according to the volume of the feldspars present which belongs to the orthoclase group; the feldspar-feldspathoid and the feldspathoid groups belonging to both leucocratic and mesocratic divisions may be submitted to threefold division based on the amount of feldspathoids present which is

TABLE III.

ROCK SERIES.

Div.	Group.	Series.	Percentage Feldspar Orthoclase.	Percentage Feldspathoid Leucite.	Percentage Ferromagnesian Silicate Olivine.	Percentage Ore Sulphide.
A	*a*	I.	——	——	——	——
	b	II.	100–67			
		III.	67–33			
		IV.	33–0			
	c	V.	100–67			
		VI.	67–33			
		VII.	33–0			
	d	VIII.		100–67		
		IX.		67–33		
		X.		33–0		
	e	XI.		100–67		
		XII.		67–33		
		XIII.		33–0		
B	*f*	XIV.	100–67			
		XV.	67–33			
		XVI.	33–0			
	g	XVII.		100–67		
		XVIII.		67–33		
		XIX.		33–0		
	h	XX.		100–67		
		XXI.		67–33		
		XXII.		33–0		
C	*i*	XXIII.			0–33	
		XXIV.			33–67	
		XXV.			67–100	
	j	XXVI.			0–33	
		XXVII.			33–67	
		XXVIII.			67–100	
	k	XXIX.				100–67
		XXX.				67–33
		XXXI.				33–0

leucite; the ferromagnesian silicate and the ferromagnesian silicate-ore groups are divisible on the basis of the quantity of ferromagnesian silicates present belonging to the olivine group; and a division of the ore group may be based upon the proportion of ore which is sulphide. Table III. shows this classification.

It will be noted that the series in Table III. have not been named, but only numbered. This is due to the fact that the natural definitive names are in many instances unwieldy. For example, series X., XIX. and XXII. would be the "Other Feldspathoids than Leucite" series of their respective groups, and series XXIV. and XXVII. would be "Olivine-Other Ferromagnesian Silicates" series. A less cumbersome nomenclature is suggested in the succeeding section, and still more suitable ones may possibly be devised, but the classification is worthy of consideration on its own merits irrespective of the names which may be applied to its subdivisions. It commends itself because it is a simple and consistent quantitative classification and follows in a general way the qualitative classification at present in use.

III. NOMENCLATURE OF IGNEOUS ROCKS.

It is evident that short series names must be applied before the classification outlined in the preceding section can attain its full usefulness. New names are undesirable when they can possibly be avoided, and since the present mineralogical classification of rocks is rarely more than roughly quantitative, it seems justifiable to give the old names definite quantitative meanings which shall be as far as possible in line with common usage. This has been attempted in Table IV.

In this table, the phanerite of each series is named first and joined by a hyphen to the corresponding aphanite, when such is known to exist. Lines indicate the inability of the writer to find old names expressing in a general way the compositions indicated by the classification. Parentheses enclose old names which fit the classification but with which there are reasons for dissatisfaction. Thus the writer agrees with Cross[1] that compound names, like

[1] *Am. Jour. of Sci.* [4], *4* (1897), 120 and 123.

leucitephonolite and leucitenephelitetephrite, should be restricted to mineralogical varieties and not applied in a general way, and that rock names derived from mineral names, like nephelinite, should be reserved for rocks consisting essentially of those minerals. Then, too, the members of the ore series are commonly called by such names as "igneous magnetite" and "igneous pyrrhotite," but it would seem preferable to have distinct series names for them as in the cases of the other rocks.

When a logical classification is forced upon an inconsistent set of names, it is inevitable that the meanings of some of them shall be shifted to a certain extent. So in Table IV. it will be found that the series of the quartz-feldspar group—granite-rhyolite, adamellite-dellenite, and granodiorite-dacite—have been so placed that they include all the highly quartzose rocks commonly referred to them, but exclude some rocks low in quartz heretofore classed under them. Similarly, rocks low in feldspathoids have been excluded from the leucocratic feldspar-feldspathoid series; and both the low feldspathoid and the low quartz rocks thus removed from their customary positions have been made parts of the leucocratic feldspar series. These, together with other changes that will be noted, have all been made consistently with the object of giving the old names definite quantitative meanings.

The typical rocks of the new series are to be understood as consisting of the same materials as the typical rocks of the old, present in such proportions as to place the rocks about the center of the new ranges. For example, in granite the range is from 0 to 33 per cent. of melanocratic minerals and from 0 to 33 per cent. of the feldspars plagioclase, so a rock in the center of the range will contain both melanocratic minerals and plagioclase. Granite as defined by the old classification consists of quartz and orthoclase with a little biotite, muscovite, and oligoclase. Thus we may define the typical granite of the new series as consisting of about five twelfths quartz, five twelfths feldspar, and one sixth biotite and muscovite, with about one sixth of the feldspar oligoclase. The case of syenite is similar in so far as the quantities of dark minerals and of plagioclase are concerned, but there is a

QUANTITATIVE MINERALOGICAL CLASSIFICATION OF HOLOCRYSTALLINE IGNEOUS ROCKS.

TABLE IV.

Division.		Group				Series.		
Name.	Percentage Rock which is Leucocratic Minerals.	Name.	Percentage Leucocratic Minerals which is: Quartz.	Feldspar.	Feldspathoid.			
A. Leucocratic	100–67	a. Quartz	100–67	0–33	—	I. Beresite.		
						Percentage Feldspars which is Orthoclase Group		
		b. Quartz-Feldspar	67–33	33–67	—	100–67 II. Granite-Rhyolite	67–33 III. Adamellite-Dellenite	33–0 IV. Granodiorite-Dacite
		c. Feldspar	33–0	67–100	33–0	V. Syenite-Trachyte	VI. Monzonite-Vulsinite	VII. Diorite-Andesite
						Percentage Feldspathoids which is Leucite		
		d. Feldspar-Feldspathoid	—	33–67	67–33	100–67 VIII. — - (Leucitephonolite)	67–33 IX. — - Leucitophyre	33–0 X. Foyaite-Phonolite
		e. Feldspathoid	—	0–33	100–67	XI. Fergusite	XII. Arkite	XIII. Urtite
						Percentage Feldspars which is Orthoclase Group		
B. Mesocratic	67–33	f. Feldspar	33–0	67–100	33–0	100–67 XIV. Shonkinite-Minette	67–33 XV. Kentallenite-Limonite	33–0 XVI. Gabbro-Basalt
						Percentage Feldspathoids which is Leucite		
		g. Feldspar-Feldspathoid	—	33–67	67–33	100–67 XVII. — - Orendite	67–33 XVIII. — - (Leucite-nephelitetephrite)	33–0 XIX. Theralite-Tephrite
		h. Feldspathoid	—	0–33	100–67	XX. Missourite-Wyomingite	XXI. — - Tuscalite	XXII. Ijolite-(Nephelinite)
			Percentage Melanocratic Minerals which is: Ferromagnesian Silicates.		Ore.			
						Percentage Ferromagnesian Silicates which is Olivine Group		
C. Melanocratic	33–0	i. Ferromagnesian Silicate	100–67		0–33	0–33 XXIII. Perknite	33–67 XXIV. Picrite	67–100 XXV. Peridotite
		j. Ferromagnesian Silicate-Ore	67–33		33–67	XXVI. Jacupirangite	XXVII. Cumberlandite	XXVIII. Dunite
						Percentage of Ore which is Sulphide Group		
		k. Ore	33–0		67–100	100–67 XXIX. (Igneous Sulphide)	67–33 XXX. (Igneous Oxide-Sulphide)	33–0 XXXI. (Igneous Oxide)

range of from 33 per cent. leucocratic minerals quartz through no quartz and no feldspathoids to 33 per cent. feldspathoids to be considered. Obviously a rock in the center of this range will be free from both quartz and feldspathoid. Typical syenite of series V. may therefore be defined as consisting of about five sixths feldspar and one sixth hornblende, with about five sixths of the feldspar orthoclase and one sixth oligoclase. These two examples suffice to show the method of determining the compositions of the typical rocks of the new series.

The word "about" as used in the preceding paragraph is intended to mean that the quantities qualified by it may vary slightly from the proportions named but not by an essential amount. The amount of mineral which is to be considered essential in this classification is determined by the smallest amount which can possibly affect the classification. This amount will only be effective in the middle series of the middle group of the middle division and then only when a rock is on the border line of division, group, and series. That is to say, a rock that just falls in the mesocratic division because it contains 33 per cent. leucocratic minerals, and just falls in the feldspar-feldspathoid group because 33 per cent. of these are feldspathoids, and finally just falls in the leucitenephelitetephrite series because 33 per cent. of its feldspathoids are leucite, will have been classified on the basis of 3.3 per cent. leucite. 3 per cent. leucite would have thrown it into another series and 4 per cent. would have been necessary to ensure its getting into the leucitenephelitetephrite group. 4 per cent. is thus the minimum volume that can affect classification under the proposed system and will be considered as "essential" in this paper.

Knowing the mineral composition of the typical rocks of Table IV. and that 4 per cent. constitutes an essential amount of a mineral, the holocrystalline igneous rocks may be named by the aid of four simple rules. (1) When a leucocratic rock does not contain an essential quantity of melanocratic minerals, put before its name the adjective "leucous"; and when a melanocratic rock does not contain an essential amount of leucocratic minerals, place

the adjective "melanous" before its name. For instance, a syenite with but 2 per cent. hornblende would be a *leucous syenite.* (2) When a rock belongs to a series whose type contains a member of a mineral group not essential to that series and the rock itself contains neither this nor any other member of the same group in essential amount, the name of the missing mineral, connected by a hyphen to the word "free," should be placed before the name of the rock. For example, a syenite containing no oligoclase or other member of the plagioclase group is an *oligoclase-free syenite.*

The two remaining rules apply to the use of mineral modifiers prefixed to the name of the type rock and connected with it by a hyphen. (3) If a rock contains in place of the mineral present in the type another mineral of the same group, prefix that mineral name to the type name. That is to say, if a syenite contains biotite instead of hornblende, call it *biotite-syenite.* As corollaries to this rule, it should be noted that a syenite containing essential volumes of both hornblende and biotite would be *hornblende-biotite-syenite;* that a granite containing muscovite as its one melanocratic mineral—when the type contains biotite also—would be a *muscovite-granite;* and that a granite containing hornblende as its sole dark mineral would be a *hornblende-granite.* (4) If a rock contains an essential amount of a mineral belonging to a group not present in the type, the name of the mineral should be prefixed. For instance, a syenite with 10 per cent. of nephelite is a *nephelite-syenite.* When modifiers are applied according to both Rule 3 and Rule 4, that of Rule 3 should be given precedence. For example, a nephelite-syenite whose dark mineral was biotite would be *biotite-nephelite-syenite.*

IV. POSSIBLE EXTENSIONS OF NOMENCLATURE.

For general practical use it would seem that no further names were necessary at present. By those engaged in specialized work in petrography, however, the use of qualifying adjectives and mineral modifiers may be found too unwieldy in some instances and extensions of the system be considered desirable.

The extension which suggests itself as being the most logical

TABLE V.

SUBCLASSIFICATION OF SERIES I. TO VII., TABLE IV.

Percentage of Rock Designated by

TABLE V.

SUBCLASSIFICATION OF SERIES I. TO VII., TABLE IV.

Percentage of Rock Designated by "r" and Percentage of Leucocratic Minerals by "f" which is:			Percentage of Rock which is Melanocratic Minerals.	Subseries.				
Quartz.	Feldspar.	Feldspathoid.						
100f–96f	0–4r	—	0–4	(Series I) 1. Igneous Quartz				
100f–96f	0–4r	—	4–33	2. Esmeraldite				
96f–67f	4r–33f	—	0–4	3. Alaskite-Tordrillite				
96f–67f	4r–33f	—	4–33	4. **Beresite-** ——				
				Percentage of Feldspars which is Orthoclase Group				
				100–96	96–67	67–33	33–4	4–0
67f–33f	33f–67f		0–4	(Series II) 5. —— - ——	7. Granitelle-Eurite	(Series III) 9. —— - ——	(Series IV) 11. —— - ——	13. — - —
67f–33f	33f–67f	—	4–33	6. —— - ——	8. **Granite-Rhyolite**	10. **Adamellite-Dellenite**	12. **Granodiorite-Dacite**	14. Tonalite
33f–4r	67f–96f	—	0–4	(Series V) 15. — -Lindöite	17. —— - ——	(Series VI) 27. —— - ——	(Series VII) 33. —— - ——	35. — - —
33f–4r	67f–96f	—	4–33	16. —— - ——	18. Nordmarkite- —	28. Banatite-Domite	34. — -Malchite	36. — - —
4r–0	96f–100f	4r–0	0–4	19. Orthoclasite-Sanidinite	21. — -Lestiwarite	29. —— - ——	37. —— - ——	39. Plagioclasite
4r–0	96f–100f	4r–0	4–33	20. —— - ——	22. **Syenite-Trachyte**	30. **Monzonite-Vulsinite**	38. **Diorite-Andesite**	40. Anorthosite- —
—	67f–96f	33f–4r	0–4	23. —— - ——	25. —— - ——	31. —— - ——	41. —— - ——	43. — - —
—	67f–96f	33f–4r	4–33	24. Pulaskite	26. Hedrumite- —	32. Miaskite-Kulaite	42. Litchfieldite- —	44. Mariupolite- —

one to apply first is one making subseries out of those rocks that contain, and those that lack, essential volumes of mineral groups which may be either present or absent in the series. For instance, the syenite-trachyte series contains: rocks with an essential amount of melanocratic minerals and rocks devoid of them, rocks with no quartz and rocks with an essential volume of it, rocks containing an essential volume of feldspathoids and rocks with none, and rocks lacking in plagioclase and those containing it as an essential. Simple names for such subseries would undoubtedly be useful in some cases, and perhaps particularly so in the case of the more abundant rocks which occur in Series II. to VII. inclusive. Table V. presents a subclassification into subseries of Series I. to VII. inclusive.

Such of the rock names in present use as can be fitted to the subclassification without too great distortion of meaning are shown in the table, but numerous lines call attention to the fact that if such a subclassification is to come into use many new names must be coined. The subseries classification removes entirely the necessity for applying Rules 1 and 2 proposed for nomenclature under the series classification. Rules 3 and 4 will continue to be useful, but since in the case of the subclassification they apply to typical rocks of the subseries instead of to those of the series, the number of mineral modifiers required will be greatly decreased.

Many other possible extensions of nomenclature will suggest themselves to petrographers. For example, names based on the proportion of albite to soda-lime feldspars might be applied to rocks containing plagioclases. It is advisable, however, to avoid extending the nomenclature whenever possible and to introduce extensions only when they seem necessary in the interest of clear definition.

V. APPLICATION TO TEXTURAL CLASSIFICATION OF IGNEOUS ROCKS.

The system developed for the quantitative mineralogical classification of igneous rocks may be employed to render their textural classification quantitative. The method is shown in Table VI.

TABLE VI.

TEXTURAL CLASSIFICATION OF THE IGNEOUS ROCKS.

A. Holocrystalline Rocks.

Name.	Phanerocrystalline, Per Cent.	Microcrystalline, Per Cent.
Phanerite	100–96	0–4
Phanerite Porphyry	96–67	4–33
Aphanite Porphyry	67–33	33–67
Aphanite	33–4	67–96
Holoaphanitic Aphanite	4–0	96–100

B. Hyaline Rocks.

Name	Crystalline, Per Cent.	Hyaline, Per Cent.
Phanerite or Aphanite	100–96	0–4
Aphanite Vitrophyre	96–67	4–33
Phenocryst-Porphyry	67–33	33–67
Glass	33–4	67–96
Holohyaline Glass	4–0	96–100

In using Table VI., *A*, the name of the series to which a rock belongs is to be determined by Table V. Then, from a consideration of the relative volume of the rock which is phanerocrystalline, its position in Table VI., *A*, is determined, and the word "aphanite" or "phanerite" in this table replaced by the appropriate name. Thus a rock with the mineralogical composition of typical syenite and trachyte which was 75 per cent. phanerocrystalline would be a *syenite porphyry* and one which was 97 per cent. microcrystalline a *holoaphanitic trachyte.*

A similar procedure is to be followed with the first two members of Table VI., *B*, but the other terms require a few words of explanation. In place of the word "phenocryst," the names of all minerals present in essential amount are to be placed and connected by hyphens. For the word "glass," the name of the particular kind of glass present is to be substituted—as obsidian, pitchstone, perlite, pumice, tachylyte. Then a hyaline rock containing 75 per cent. of crystals of quartz, orthoclase, oligoclase and biotite in the proportions in which they occur in rhyolite would be a *rhyolite vitrophyre,* with only 50 per cent. crystals it would be a *biotite-oligoclase-orthoclase-quartz-porphyry,* provid-

ing all the minerals were represented in essential quantities, with 25 per cent. crystals and the glass obsidian it would be *obsidian,* and with 2 per cent. crystals *holohyaline obsidian.*

VI. APPLICATION TO SEDIMENTARY ROCKS.

The clastic sedimentary rocks readily lend themselves to threefold quantitative division. They have not, however, been studied in such detail as the igneous rocks, so the classification can not be carried far at present without making extensive additions to the nomenclature. In the expectation that the investigation of sedimentaries will continue until they are as well known as the igneous rocks, the amount of mineral to be considered essential in the former may be kept the same as that in the latter—namely 4 per cent. A quantitative mineralogical classification of the more common clastic sedimentary rocks is presented in Table VII.

TABLE VII.

QUANTITATIVE MINERALOGICAL CLASSIFICATION OF SEDIMENTARY ROCKS.

Name.	Percentage Calcite.	Percentage Clay.	Percentage Quartz Sand.	Percentage Feldspar Sand.
Limestone	100–96	0–4		
Argillaceous limestone	96–67	4–33		
Marl	67–33	33–67		
Calcareous shale	33–4	67–96		
Shale	4–0	96–100	4–0	
Arenaceous shale		67–96	33–4	
Flagstone		33–67	67–33	
Argillaceous sandstone		4–33	96–67	
Sandstone		0–4	100–96	0–4
Feldspathic sandstone			96–67	4–33
Arkose			67–33	33–67

The system may be applied with advantage to other gradational series of sedimentary rocks. For example, the carbonaceous rocks may be classified as shown in Table VIII.

TABLE VIII.

CLASSIFICATION OF SEDIMENTARY CARBONACEOUS ROCKS.

Name.	Per Cent. Shale	Per Cent. Coal.
Shale	100–96	0–4
Bituminous shale	96–67	4–33
Bone	67–33	33–67
Coal	33–0	67–100

VII. APPLICATION TO METAMORPHIC ROCKS.

The application of the quantitative mineralogical system to metamorphic rocks may be made largely along the same lines that were followed in applying it to the sedimentary and igneous rocks.

The gneisses may be given the names of the phaneritic igneous rocks which are their mineralogical equivalents as suggested by Gordon.[1] Then a gneiss with the mineralogical composition of a granite is a *granite gneiss*. It seems advisable to use such names as indicative of mineral composition and structure only, irrespective of origin, rather than to apply modified or different names to rocks of identical compositions and structures but different origins as has been further suggested by Gordon. Differences in origin may then be readily indicated by qualifying adjectives.

The writer would suggest that schists might in like manner be given the names of mineralogically equivalent aphanites.

Turning next to metamorphosed sediments, quartzite, feldspathic quartzite, and greywacke would have the mineralogical compositions of sandstone, feldspathic sandstone and arkose as shown in Table VIII. Similarly the metamorphic equivalents of the carbonaceous sediments—bituminous shale, bone, and coal—in Table IX. would be carbonaceous slate, anthracite bone, and anthracite.

Many other applications might be mentioned, but those given are sufficient to illustrate the value of the method.

VIII. SUMMARY.

Quantitative mineralogical classifications of gradational series of rocks may be constructed on the basis of the threefold division of two components or groups of components. According to this method, a first division is made with from none to one third by volume of a certain component or group of components, a second division with from one third to two thirds, and a third division with from two thirds to all of that component or group of components. Such partition may be continued as long as the resulting subdivisions contain more than a single component.

[1] *Bull. Geol. Soc. of Am.*, 7 (1896), 122.

In the proposed classification of the igneous rocks, the threefold division is employed three times as shown by Tables I., II. and III., producing 3 divisions, 11 groups and 31 series. When the subdivision is carried to this extent it is possible that the presence of a little over one third of one third of one third of a mineral, or about 4 per cent., may affect the classification. This volume is considered an essential amount in all the classifications.

Some of the rock names in present use in a qualitative or very general quantitative way may legitimately be given definite quantitative meanings. One possible arrangement is suggested in Table IV. With such a table and a knowledge of the typical mineral compositions of the rocks in each series, all varieties of holocrystalline igneous rocks may be named by the use of adjectives and mineral modifiers with the aid of four simple rules. The classification may be extended as desired. One possible extension is shown in Table V. A means of applying threefold division to the textural classification of crystalline and hyaline igneous rocks is presented in Table VI.

Illustrative applications of the method of threefold quantitative division to sedimentary rocks are shown in Tables VII. and VIII. Means of applying it to metamorphic rocks are discussed in the preceding section.

It is highly desirable that the mineralogical classification of rocks be placed on a quantitative basis. The classifications developed in this paper are simple, logical, and flexible, and can be introduced without increasing the nomenclature. General employment of the proposed classifications would aid definition and tend to prevent confusion, facilitate study and advance research.

SECONDARY ENRICHMENT IN THE CALEDONIA MINE, CŒUR D'ALENE DISTRICT, IDAHO.

EARL V. SHANNON.

The Caledonia mine of the Cœur d'Alene district, Idaho, is located in the high mountainous country east of Deadwood Gulch.

The mine became a producing property in 1909, and has yielded considerable high grade silver, copper, and lead ore. At present it is closed, pending the hearing of an injunction entered against the Caledonia Company by the Bunker Hill and Sullivan Company, and conditions for a more careful study of the property are not favorable. The following notes on the changes of the character of the ores with depth are, I believe, of interest and supplement in some measure the observations of Hershey in this region. Of this vein Hershey says:[1]

"The Caledonia vein, probably a portion of the Sierra Nevada vein, . . . is extremely crooked and is cut by many faults of small throw that do not seriously disturb its general position. There is always at least a little gouge, with small quartz lenses distributed along it, and more or less quartz in seams and pockets in the neighboring quartzite, often extending 10 to 20 feet from the fissure proper. In a few places where it is parallel to the stratification, the gouge is very thin and the mineralization light. Galena seems to have been developed largely in distinct shoots, but tetrahedrite seems to have been much more thoroughly distributed along the vein, which may be an indication of two periods of mineralization. The metal salts have been largely leached from the vein near the surface and carried down to enrich the lower portion of the oxidized zone. Thus we find much limonite in the vein near the surface, but not much of silver or lead minerals and no visible copper mineral. In descending on the ore-shoot, lead carbonate and silver salts become apparent and even much native silver appears in places. Lower, oxidized copper minerals are added to these and small bunches of very rich ore are found. The copper comes from tetrahedrite. Some of this is said to assay as high as 3,000 ounces silver per ton. The main ore-

[1] Hershey, Oscar H., "Genesis of the Lead-Silver Ores in Wardner District, Idaho," Mining and Scientific Press, June 1, 8, 15, 1912.

shoot, characterized by much galena ore of high grade, is about 400 feet long by the crooks of the vein, and its western limit goes down on a course S. 15° E. It is flanked by less definite shoots characterized by rich tetrahedrite with little or no galena."

The mine is developed from an inclined shaft and all of the ore was taken from stopes above the 500-foot level. Recently a tunnel driven from the bottom of Deadwood Gulch has encountered the vein, but no ore has yet been shipped from the lower level.

Limonite, though abundant, is present in smaller amounts than in the neighboring mines in Revett quartzite. It is associated with considerable amounts of oxide of manganese as a stain or impregnation in quartzite or as dendritic delineations on rock surfaces. This occurrence of manganese is peculiar to this vein and the neighboring Sierra Nevada vein, not occurring, so far as known, in any other vein in the district.

At the highest point in the vein where ore minerals were noted, they occurred as cerussite and massicot in the broader portions and as peculiar waxy limonite with an occasional crystal of pyromorphite where the vein thins parallel to the bedding. As exposed in the stopes and raises above the Omaha level, the parent fissure is characterized by relatively firm walls and, disregarding the minor contortions, describes a broad curve. The upper parts of the ore-shoots coincide fairly well, in dip and strike, with the main fissure. The lower parts of the ore-shoots have been displaced by cross faults which apparently have changed the effective dip. As recorded by Hershey, the ore-shoots improved in size and richness with depth, and copper made an appearance in the form of radial bunches of malachite and delicate azurite stains on cerussite. The silver values in this zone were present mainly in massicot or as native silver. In hardened portions of the ledge in the vicinity of the 300-foot level and downward, there were found residual bunches of cuprite, surrounded by malachite, in sufficient amount to make it profitable to sort the copper ore from the lead ore. In other places the ore showed small cores of tetrahedrite surrounded by concentric zones of cuprite, malachite and azurite. These masses were surrounded by leached granular material.

In the Dodd stope, above the 300-foot level, a considerable shoot of soft white gouge containing large crystals of glassy cerussite, was bottomed by a zone of rich tetrahedrite.

Silver in native form is widely distributed, but was much more common with oxidized lead ores than with copper minerals, although the "gray copper" often carried high values in silver. In the Taylor stope, rich pipes narrowing upward, were lined with brilliant cerussite crystals covered with a thick mat of finely felted wires of native silver. Silver occurred, also, as bright wires, imbedded in soft spongy siliceous limonite. According to a reliable miner, six sacks were filled with coarse blackened native silver from a series of flat pockets on the footwall. In the Joe stope, below the 300-foot level, numerous long strings of bright native silver were seen hanging from cracks in shattered altered quartzite. Lower, in the Boyle stope, silver in a white clay gouge was intimately mixed with nuggets of native copper.

The constant high silver values in the yellow massicot have led to a misconception in regard to its mineralogical nature, the material being called "chlorides" when yellow, and "bromides" when stained blue or green by copper. Likewise cuprite in certain associations is called "ruby silver" and the sooty covellite is "sulphurets" of silver. In view of the high silver values present, it is remarkable that silver minerals, other than the native metal, were not formed in bodies of some size. Tests of every specimen of the supposed ruby silver which could be obtained proved it to be cuprite and relatively low in silver content except when containing tetrahedrite. The abundant occurrence of the sulphur-yellow massicot in the same deposit, although not intimately associated with tetrahedrite, suggested that it might be bindhiemite which forms at some places in the oxidation of galena-tetrahedrite ores, but analysis shows the mineral to be relatively pure lead oxide, containing only insoluble silica, silver, and rarely a limonite or copper stain. Since no negative radicle is present to form a compound with the silver the conclusion is warranted that this metal occurs as native silver in part as visible grains, but in the main as particles of microscopic size. Silver is certainly present in the sooty covellite or "black sulphurets," but

is so included in the copper mineral that it is impossible to identify any particular silver compound. In the upper zone, wherever tetrahedrite was observed oxidizing in place, the oxidation has been accompanied by the removal of silver almost completely from the oxidized copper compounds. This silver was evidently deposited elsewhere, either as native silver or as a compound which has subsequently decomposed, leaving pure silver. The greater portion of the silver associated with the massicot and cerussite may be assumed to have formed as a result of oxidation of argentiferous galena, but some silver was probably added by descending argentiferous solutions.

Some of the shoots of galena mentioned by Hershey have crusts of argentiferous covellite coating the upper surface and extending downward along cracks toward the center of the masses. Such coatings vary in thickness from one sixteenth of an inch to six inches or more, and consist of fairly compact material of sooty appearance. In color they are deep indigo to black, and they contain specks of pyrite and masses of glassy cerussite. The cerussite is equally abundant in covellite and in galena. Apparently it replaces galena or siderite that is associated with galena.

In several stopes above the 500-foot level tetrahedrite was present in great abundance and nearly everywhere it covered cores of chalcopyrite. In one stope this was particularly striking, the ore ranging from relatively pure chalcopyrite coated along cracks with thin films of tetrahedrite, through coatings of increasing thickness, to masses of tetrahedrite containing ragged remnants of chalcopyrite. As a rule limonite is present when chalcopyrite is replaced by tetrahedrite.

In the lowest ore opened the characteristic composition is replaced by "steel" galena of varying fineness containing broken masses of quartz and disseminated crystalline grains of buff siderite, and with blotches of chalcopyrite and tetrahedrite in the more quartzose portions. Much of the ore is in relatively firm sheets and is inclosed in a very soft crushed quartzite gangue. Chalcopyrite and tetrahedrite occur also in distinct masses, but other bunches show apparent replacement similar to that observed

above, but without any limonite. This ore may not be entirely unaffected by secondary processes, and no exact conclusions may be drawn regarding the relative proportions of the primary minerals, but it would seem from the appearance of the ore that some of the tetrahedrite is primary but the greater part occurs as a replacement of chalcopyrite which may be all original or may be, in part at least, a product of the enrichment of pyrite by descending solutions.

In an examination of the limited literature available to me, I have found no record of covellite replacing galena. Lindgren, in writing of the Clifton-Morenci District of Arizona, mentions covellite as the first mineral formed in the replacement of sphalerite by sulphatic copper solutions. The replacement of chalcopyrite by tetrahedrite is likewise not mentioned in the literature at hand. W. H. Weed found tetrahedrite associated with primary chalcopyrite in the Butte district, but does not describe its paragenesis in detail.

If we assume that chalcopyrite was present in the primary ore of the eroded and oxidized portion of the vein, in amounts equal to or greater than tetrahedrite, it is apparent that a concentration of the antimonial mineral has taken place with no corresponding concentration of the non-antimonial minerals.

From the above it seems highly probable that the ore of the Caledonia mine has been enriched by secondary processes. It is noteworthy that neighboring veins have not undergone a similar enrichment. The only mineralogical difference apparent is the smaller amount of siderite present in the primary ore of the Caledonia mine and the presence of a little more chalcopyrite and considerably more tetrahedrite than in the surrounding veins. I have always considered that the presence of much siderite would prevent a concentration of the copper that is sparingly mixed with the lead ores of this district, for the copper solutions would attack siderite and the insoluble copper carbonates would be precipitated. The precipitation of secondary minerals by carbonates would prevent also the development of much secondary sulphide ore. If we suppose that the decomposition of tetrahedrite forms antimonial solutions whose affinity for copper is greater than the

affinity of the CO_2 present, we have a possible explanation of the concentration of tetrahedrite. If the gradually increasing antimonial copper solutions descend and replace the primary chalcopyrite, there would be a correspondingly decreased amount of chalcopyrite remaining to be exposed to ordinary oxidizing agencies.

It is possible that the erosion of the surface was checked and that high-grade tetrahedrite ore accumulated in a zone having a definite vertical extent, at what was at that time the level of ground water. Renewed rapid cutting may have caused the ground water level to fall away from this zone. From physiographic studies of the region, it is thought that the river, at one time, had its course almost over the top of the place where the shaft house now stands, and that, at a later time, periods of rapid erosion have alternated with periods of less rapid erosion. This is suggested by terraces at several levels on the sides of the valley. It would seem that the solvent action of the downward moving solutions in the ore body was not sufficient to keep pace with the downward moving water level, and that only the minerals from the more fractured portions of the lode were removed, leaving those in the less permeable portions to undergo a slower oxidation. Thus apparently the sulphide ore has been marooned above the water level.

The covellite present as a replacement of galena is probably the most recent of the secondary sulphides and is not the result of any extensive concentration. Probably it formed by the action of descending copper sulphate waters. This, for reasons above stated, could occur only after most of the siderite had been removed by circulating waters or fixed as insoluble carbonates and oxides.

ELECTROCHEMICAL ACTIVITY BETWEEN SOLUTIONS AND ORES.[1]

ROGER C. WELLS.

In a recent paper in this journal Gottschalk and Buehler clearly proved that an interesting connection exists between the electromotive behavior of sulphides and their rates of oxidation when in contact.[2] It is my purpose here to call attention to electromotive action of a different sort, namely, that caused by different solutions acting either on a single mineral or on a combination of minerals.

The apparatus required to show this action is extremely simple and is represented in the accompanying sketch (Fig. 52). *A*

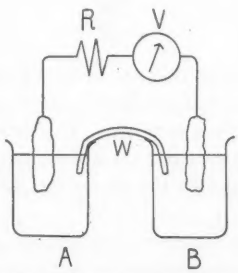


FIG. 52. Apparatus employed to show electromotive action.

and *B* are small beakers containing the solutions to be investigated, *R* is a resistance, *V* a millivoltmeter and *W* a wick saturated with a neutral salt to make electrical connection between th solutions in *A* and *B* without admixture. The arrangement may be altered as desired, to study the effects of an applied current or to record the currents developed by various combina-

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] "Oxidation of Sulphides," ECON. GEOL., 7, 28, 1912.

tions. For most purposes it suffices to suspend the mineral electrodes by platinum wires but many other ways of mounting them suggest themselves such as sealing into wax and completely immersing them. In this arrangement I have merely substituted conducting minerals for platinum in the device well known to electrochemists as the "chemometer."[1]

To illustrate the behavior with electrodes of pyrite the following experiment may be mentioned. In *A* was placed an acidified solution of ferric sulphate, in *B* sodium sulphide, both solutions being approximately normal. The total resistance of the whole circuit was brought to 3,000 ohms, which is comparable to the resistance of some geologic strata. On closing the circuit the following electromotive forces and currents were noted.

OXIDATION AND REDUCTION CURRENT WITH ELECTRODES OF PYRITE.

Time, Minutes.	Electromotive Force, Volts.	Current, Milli-amperes.
0.1	1.04	0.34
1.0	1.02	0.33
5.0	1.00	0.33
10.0	1.00	0.33

It is perfectly obvious that the source of this current lies in the possibility of reduction of the ferric solution and the simultaneous oxidation of the sodium sulphide. The experiment at once suggests a wealth of interesting variations, particularly with reference to the part played by the electrodes, and the effect of other solutions.

Before describing further experiments along these lines it seems appropriate to emphasize the fact that oxidation and reduction effects must always be present in electrochemical action, whatever the solutions or the minerals. Now the solution-products of ore-forming minerals are in general either oxidizable or reducible substances. Accordingly, the expression "electromotive force of a mineral" is rather indefinite unless it is clearly understood that no other active substances are present than the proper solution-products of the mineral. On the other hand if other active substances are present they may produce noteworthy

[1] W. Ostwald, *Zeitschr. physik. Chem.*, 15, 399, 1894.

electrochemical effects. In fact, in general, it seems as if the effects due to the different solutes of migrating waters would far outweigh the electrical action of the solution-products of the ores themselves.

In regard to the production of currents with the above apparatus it was found that solutions which are ordinarily thought of as capable of fairly easy oxidation and reduction furnish the largest currents. With other solutions, such as acids, alkalies and simple salts, polarization soon sets in leaving only a small "residual current" flowing. The currents yielded by different minerals in the same solution are about the order of "residual" currents. The following data represent the effects under conditions similar to the above with electrodes of marcasite and galena, both dipping into potassium chloride solution.

CURRENT PRODUCED BY MARCASITE AND GALENA IN POTASSIUM CHLORIDE.

Time, Minutes.	Electromotive Force, Volts.	Current, Milli-amperes.
0.1	0.20	0.07
1.0	0.10	0.03
5.0	0.06	0.02
10.0	0.06	0.02

The principles of electrochemistry enable us to state that when a combination functions as cathode, a reduction must occur, and likewise at the anode an oxidation. An interesting point is to determine whether these changes occur in the constituents of the solution, the mineral or both. I have found that the distribution of these changes depends upon the nature of the mineral, the nature of the solution, and the intensity of the current. With the more resistant minerals such as pyrite and chalcopyrite combined with oxidizable and reducible solutions, the changes occur almost wholly in the solutions. On the other hand if the minerals are more attackable, like pyrrhotite, chalcocite, galena, and niccolite, they are increasingly affected, the more so if the solutions are not capable of ready oxidation or reduction. Chalcocite seems to be exceptionally capable of both oxidation and reduction. Even when the principal action of a solution is a direct attack of the mineral there may still be electrical activity in addition, if the

proper circuits are present. That a change of current density may alter the products is shown by the fact that feeble currents generate hydrogen sulphide from certain sulphides as cathodes in acid solution while stronger currents evolve chiefly hydrogen. Naturally, the decomposition of sulphides as anodes is enormously greater than that occurring when they function as cathodes, for in the latter case they are protected by the hydrogen sulphide formed.

When solutions of the valuable metals are introduced into one of the beakers above mentioned notable effects are obtained. Gold may not only be plated out upon minerals but generates an appreciable current spontaneously by depositing. Silver follows with a lower intensity and copper with a very slight depositing tendency indeed. The introduction of sodium sulphide into beaker *B*, however, is amply sufficient to precipitate copper from a copper solution in beaker *A* upon sulphides. With very feeble currents, however, cupric sulphide forms instead of the metal. If copper salts are present in beaker *B* with a pyrite electrode and a vigorous oxidizing agent is added to *A* a metathetical reaction occurs slowly between the pyrite and the copper salt producing a thin film which is believed to be copper sulphide on the pyrite. In pure ferrous sulphate, however, pyrite appears to be fairly well preserved as anode. As cathode in most solutions pyrite retains its luster surprisingly.

The deposition of a silver "tree" by chalcocite recently described by Palmer and Bastin[1] appears clearly to depend in part on electrochemical action. There is a tendency for the silver to deposit on itself as cathode, while the cuprous ions undergo oxidation near the chalcocite as anode. The two actions may occur some distance from each other provided only that the "tree," mineral and solution make a conducting circuit. The explanation of this action presented by Palmer and Bastin, that it is "due to oxidation through the process of hydrolysis," appears vague if not untenable.[2]

[1] ECON. GEOL., 8, 140, 1913.
[2] *Loc. cit.*, p. 168.

A most important factor in electrochemical action is polarization. In order to obtain some orienting data upon the behavior of minerals in this respect several were feebly polarized in potassium chloride solution. In studying the behavior at the cathode a zinc anode was employed, the total circuit having a resistance of 3,000 ohms, with the following results. The voltage stated is that of the whole combination.

POLARIZATION AT THE CATHODE IN POTASSIUM CHLORIDE.

Cathode.	Volts.			Milli-amperes.		
	0.1 Min.	1.0 Min.	10.0 Min.	0.1 Min.	1.0 Min.	10.0 Min.
Pyrolusite	1.31	1.29	1.17	0.45	0.44	0.40
Chalcocite	0.82	0.80	0.82	0.37	0.37	0.37
Pyrrhotite	0.83	0.73	0.69	0.27	0.24	0.23
Marcasite	0.78	0.68	0.60	0.26	0.23	0.20
Pyrite	0.76	0.63	0.62	0.25	0.21	0.21
Galena	0.61	0.55	0.48	0.21	0.19	0.16
Covellite	0.43	0.43	0.43	0.14	0.14	0.14
Platinum	0.45	0.35	0.35	0.15	0.12	0.12

That the differences in electromotive force here shown are largely due to differences in polarization seems clear from the fact that the order is different from that obtained by measuring the electromotive forces on open circuit. I shall not attempt here to go into the difficulties attending the measurement of the electromotive forces of minerals on open circuit further than to say that many specimens possess a somewhat porous structure, some even visible impurities, and that the regulation of the small concentrations which determine their potential is, under such circumstances, frequently impossible.

In a similar way the minerals were polarized as anodes in potassium chloride solution using a cathode combination of pyrite in acidified normal ferric sulphate, the total resistance being the same as above.

These results suggest an order for the effective reducing power of the minerals noted, at least when acting in an electrical way, which appears to have a real quantitative significance.

It becomes an important matter to ascertain the necessary conditions for electrochemical action of this sort in ore deposits. Of

course the two electrodes and wire pictured above might just as well be a continuous body of ore. The only remaining condition seems to be that the liquid circuit should be somewhat circuitous so that solutions of different concentration or composition could not immediately mix. This is by no means an impossible condition in a network of fissures or veins. Whether the scheme is applicable on a large geologic scale or not I leave for others to decide, certainly its practicability on a small scale is a matter of laboratory observation.

POLARIZATION AT THE ANODE IN POTASSIUM CHLORIDE.

Anode.	Volts.			Milli-amperes.		
	0.1 Min.	1.0 Min.	10.0 Min.	0.1 Min.	1.0 Min.	10.0 Min.
Iron	0.92	0.92	0.92	0.31	0.31	0.31
Copper	0.60	0.60	0.60	0.20	0.20	0.20
Silver	0.39	0.39	0.39	0.13	0.13	0.13
Chalcocite	0.39	0.35	0.35	0.13	0.12	0.12
Galena	0.39	0.33	0.25	0.13	0.11	0.08
Pyrrhotite	0.33	0.25	0.16	0.11	0.08	0.05
Covellite	0.25	0.24	0.22	0.08	0.08	0.07
Marcasite	0.23	0.08	0.03	0.08	0.03	0.01
Chalcopyrite	0.21	0.19	0.16	0.07	0.06	0.05
Pyrite	0.19	0.14	0.06	0.06	0.04	0.02
Magnetite	0.19	0.08	0.03	0.06	0.03	0.01
Gold	negligible					

As a very simple demonstration of electrical activity in the deposition of *silver* from silver sulphate by *sodium sulphide* the following experiment was performed. A few drops of silver sulphate solution were placed upon the smooth face of a large crystal of pyrite. Some distance away were also placed a few drops of sodium sulphide. The two solutions were then connected by a small U-shaped capillary tube merely filled with water. In the course of an hour crystals of silver could be distinguished on the pyrite in the silver sulphate solution. According to Palmer and Bastin pyrite itself causes no deposition of silver from a silver sulphate solution in eighteen hours. This experiment shows that associations of the valuable metals with conducting minerals may have been brought about under certain conditions by the electromotive power of reducing solutions at another point.

There is every reason to believe, from an electrochemical standpoint, that in any arrangement of this sort gold would be deposited more easily than silver. That copper may be one of the products of the same sort of action, where copper salts are involved, was proved experimentally.

Long ago the elder Becquerel noted the deposition of copper at one end of a very fine capillary, a crack in a test tube in fact, when the capillary joined a solution of copper sulphate and sodium sulphide.[1] The physicist Braun[2] clearly showed a connection between this phenomenon and electrical action, although Ostwald had considered it to be largely dependent upon the semi-permeability of the membrane of copper sulphide first formed. In any case the effect is almost certainly due to electrical activity, the chief matter in question being the location of the liquid portion of the circuit. The observation emphasizes our need of a deeper study of the phenomena of capillary systems. It is a wide jump from a crack in a test tube to a vast lode system capped at one end with free metal, interspersed with sulphides and possibly in connection at the other end with active reducing agents, but the comparison is a tempting one.

In conclusion it may be remarked that the phenomena of electrochemical action are often of a delicate nature, so that one should guard himself against applying an electrical explanation too freely. At the same time it seems impossible to avoid the conclusion that electrical action is an almost necessary accompaniment of chemical action in the alterations going on in ore deposits, giving a wider distribution to the effects. It is hoped that students of this subject will be on the lookout for such effects as might be explained by electrical action with a view to assist our theories of ore deposition.

[1] A. C. Becquerel, "Sur de nouveaux effets chimiques produits dans les actions capillaires," *Compt. Rend.*, 64, pp. 919–924; 65, pp. 51–60, 720–729; 66, pp. 77–81, 245–247, 726–924, 1066–1072 (1867–1868).

[2] F. Braun, "Electrocapillare Reactionen," *Ann. d. Physik u. Chemie*, 44, p. 507, 1891.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

FIELD AND OFFICE METHODS IN THE PREPARATION OF GEOLOGIC REPORTS.

FIELD METHODS IN THE "TIERRA CALIENTE."

Sir: I have been very much interested in reading the articles that have been appearing in the recent numbers discussing Mr. Irving's paper relative to field and office methods in the preparation of geologic reports. I have been engaged in geologic work in the Isthmus of Tehuantepec oil fields for some months past and believe that the conditions there with which the geologist has to contend are somewhat different from those cited in the foregoing papers. I notice that many of the other gentlemen say that the first requisite is a map, but I think I am correct in saying that there a map is an unknown thing till the work is completed. Unless some previous work has been done all the geologist has to work from is a plan showing the land boundaries and these are usually none too correct. Often it is necessary to go into a part of the country with no more than this plan and upon the return to make recommendations as to the property, etc. A bench mark or a tie in point is a non-occurrence. Before I give an outline of the methods employed a few words as to the topographical and geological conditions will not be amiss.

Anyone who has been in the "Tierra Caliente" of Mexico knows what the geologist is up against. The ground is low—very occasionally a few fair-sized hills, but usually no more than

the undulations of the coastal countries. Some parts have been sharply eroded and we then have a rapid succession of small hills and arroyos, the difference in elevation rarely exceeding thirty meters. The ground is overgrown with *monte;* or else it is *potrero* and as paths (what few there are) never go near any of the places which need to be visited, it is a case of cutting the way continually. Under these conditions it is very hard to locate contacts except at separated points and then make hypothetical connections. Accuracy naturally depends upon the number of contact points. For these reasons the geologic ages only are indicated on the geologic map.

It is usually the geologist's task to examine a property with a view to locating a definite structural feature, as this is the best indication of possible oil value. Probably most of the seepages are known and the natives when not perverse will lead you to these and you thus obtain a fair starting point.

A sketching case is employed for field mapping, the most satisfactory results being obtained with a Batson. A Batson case and protractor with the Glenn Smith (Army) compass and sights is an arrangement that is about the best possible. On this all the work is recorded. Of course accurate topography is out of the question but form topography can be put down and if care is exercised it will be the next best to the real thing. That a barometer is worse than useless in this work has been abundantly proved by all who have attempted its use in this region.

A starting point is obtained—whether it be a river bank, seepage, or what not as long as it is easily located again and its approximate position in the country known—then a line is run in any desired direction through the *monte* and this traversed with the aid of the case; all geological features being noted as the advance is made. This is the general practice, but each individual varies the details as he sees fit. All distances are either paced or a pedometer is used—personally I have no use for a pedometer in this country, due to the uneven character of the ground that makes even pacing an impossibility, and also to the ease with which one trips over trailing vines and goes sprawling

—throwing the pedometer out of decent running. I have used several methods of pacing, varying with the nature of the ground; where flat and decently clear, that of counting every fourth step —four steps equalling three meters; up and down hills of counting every step or every other step, making these steps a meter or a

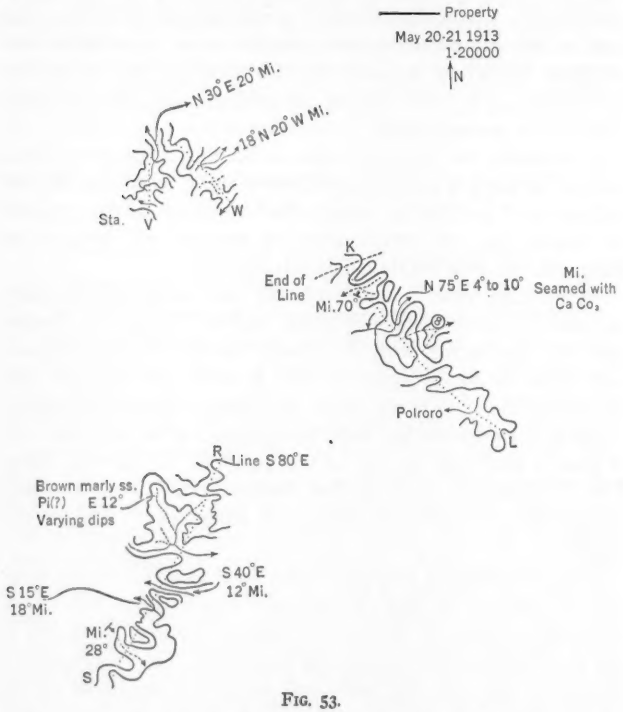


FIG. 53.

half meter. Going up hill two steps to the meter count is an excellent one. Where the country will permit the lines are cut open so as to give a straight shot with the case, and where it is not I send my *mozo* ahead about fifty meters and have him yell, sighting on the sound of his voice as it were. Greater accuracy can be obtained by this method than might be supposed.

Where it is likely that the line will be used for trying the survey, I mark a tree at every or every other station with a number and the date.

The case is fitted with a clinometer, so that the vertical angle of the sight may be measured and the paced distance corrected, but I omit this as a degree of accuracy not warranted by the broad limits of error of the pacing and also because distances paced up and down hill tend to compensate one another.

All dips, etc., are noted on the sheet either directly at the spot or by arrows off to one side or else by numbers and the observation written up in the note-book. This can be done as suits the convenience, depending somewhat on the scale used and the closeness of topographic contours on the sheet. 1–10,000 appears the easiest working scale, although I have generally used 1–20,000. This is done to avoid a later change from the 1–10,000 to the 1–20,000 which has become customary in the region.

I have attached a typical sheet (Fig. 53) from my case to illustrate the foregoing, making a few changes so as to show all methods. Instead of ordinary paper I find transparent celluloid much more satisfactory as the sheet is not damaged by wet weather. Every night or every other night the sheet is gone over in ink and the whole transferred to a large sheet, so as to show the progress of thte whole examination. Office work is reduced to a minimum, as there is nothing more to do than to trace the separate sheets accurately onto a separate map. I do not claim any originality for the above methods, but merely give them for what they are worth, hoping that they may be of some use to anyone contemplating work in similar regions.

Incidentally to manipulate a case with decent results the geologist should be able to hold the case, make the settings and draw with one hand at one and the same time. He will need the other to keep off the mosquitoes, rotadores, etc.

BURTON HARTLEY.

FIELD METHODS OF GLACIAL GEOLOGY.[1]

Sir: In the early and middle part of the nineteenth century the attention of field geologists, interested in glacial features, was

[1] Published with permission of the Director of the U. S. Geological Survey.

directed largely to the question of the extent of the drift and evidence as to its mode of deposition, whether by floating ice or by land ice. The presence of buried soils was noted at an early date, but was not recognized at first as evidence of repeated glaciation; instead it was cited as an evidence against land ice and in favor of iceberg deposition, for it was argued that land ice should have torn up all the old soil it overrode. The loess deposit which overlies a considerable part of the drift was early cited in favor of extensive submergence, though now it has come to be generally regarded as a wind deposit.

Not until the latter part of the century, when Chamberlin, Gilbert, McGee, N. H. Winchell, Upham, and others began systematic work on the drift, were moraines and other land-ice features clearly recognized and the iceberg hypothesis effectually displaced. The evidence for successive glacial stages was also brought into clear recognition. Following this and largely through investigations by the Canadian Geological Survey, it became known that the ice had more than one center of dispersion. This was known for the last stage of glaciation and inferred for earlier stages. The lobation of ice in the great valleys, early brought to notice by Chamberlin, soon gave rise to a complex lake history, to which Upham, Gilbert, Taylor, Spencer, and others had contributed important chapters by the end of the century.

It is fortunate that the glacial investigations by the United States Geological Survey were from the beginning directed by one with so broad a grasp of this intricate subject as is possessed by Dr. T. C. Chamberlin. Having made a general reconnaissance from the Rocky Mountains to the Atlantic seaboard prior to his connection with the Federal Survey, he at once outlined plans for a comprehensive mapping and study of the leading features of the glacial deposits of the entire field. By this method the knowledge of our glacial deposits has grown symmetrically and there has been a rapid unfolding of the leading events or episodes of glacial history. In this work several of the state geologists have been in close touch with Chamberlin and have consulted with him as to methods and plans. Work done under

the auspices of universities and colleges has also been brought into the same general plan. As a result there is already worked out a somewhat complete outline of glacial stages and an extensive mapping of moraines and other features for the large glacial area of northeastern United States. Detailed areal study and mapping can now be taken up and the results interpreted in relation to the broad questions and problems as well as to local ones.

In the development of North American glaciology under Chamberlin a number of cognate questions of economic value have been given attention; such for example as the relation of soil distribution to glacial history; the distribution of plant societies in relation to various types of glacial deposits and their proper successors in cultivated crops; the occurrence of underground waters and availability of such waters for public and domestic use; also locations and surroundings of valuable water powers due to glaciation. So also have questions of more purely scientific nature, such as changes of drainage and peculiarities of drainage development due to glaciation; recent uplift of parts of the glaciated region as shown by the inclination or warping of the shore lines of the glacial lakes, and the bearing of these on questions of the effect of ice weighting and ice attraction; the rate of recession of water falls and excavation of valleys in their bearing upon the length of post-glacial time, and numerous other scientific matters of more or less consequence. As outlined by Chamberlin the glacial investigations embrace a careful mapping of all moraines, outwash plains, lines of glacial drainage, eskers, kames, drumlins, and intermorainic till tracts, and all other features necessary to a complete general exhibit on a map of the structure and topography of the drift. It also embraces a study of natural and artificial exposures, of well records, and all available material bearing upon the succession of glacial formations.

In the areas covered by glacial lake waters it embraces a study of the several shore lines and their relations to lake outlets and also their relation to the ice sheet and its oscillating border; the lacustrine deposits over the entire lake are also studied sufficiently to show the extent of each of the leading types of soil. Inasmuch

as earth warping or differential uplift has affected the shore lines of a considerable part of the lake area the amount of tilting of each beach is more or less carefully studied in order to fix upon the time when uplift began, when it was most rapid, and in what direction the lines of tilt trend. This study alone embraces hundreds or even thousands of miles of travel and a large amount of careful leveling to properly interpret the nature of the uplift, its geologic relations, and time relations.

One of the first essentials to correct interpretations in glacial studies is the preparation of a complete map on the ground. It is not sufficient to note the width of a certain kind of deposit, where it is crossed by the lines traversed in the field, and then make up a map in the office, although such has been the practice of a number of glacial students who are not working under Chamberlin's direction. Such a map made up in the office is certain to be far less accurate than one on which the extent of each deposit is carefully noted in the field.

In the field one is often forced to draw upon every available line of evidence to support his mapping, because of the incompleteness of the exposures. Were the glacial geologist to publish merely an exhibit of what is shown in outcrop, as is frequently done by the stratigrapher, the map would be wholly unintelligible to persons not familiar with the particular field, even if somewhat well trained in glacial investigations. It is very necessary to determine the general drift structure in order to make an intelligible map. To do this in the absence of exposures the glacialist watches for every indication of a change of drift structure, in changes of the vegetation or character of crops, as well as in the materials brought up by burrowing animals. Constant inquiry of residents as to the soil and its relations to crops must be kept up, and knowledge obtained of borings or excavations of all classes that have been made along or near the line of route. There is thus no opportunity for the glacialist to become absorbed in meditation or otherwise preoccupied unless he stops on his trail. He must, too, with each change in drift structure, be alert in mind and ready to furnish an interpretation of the cause of

change. Otherwise, the map will become a piece of uninteresting routine work that may soon become tedious and even fatiguing.

The mapping of boundaries between different classes of glacial topography and between different kinds of drift with similar topography is done by methods adapted to each feature or deposit. In tracing the course and the limits of such a strong topographic feature as a moraine, it is hardly necessary to leave the wagon-road, the mapping being easily done on topographic maps; while in the absence of such maps distance from section lines, streams, or other ordinary map features may be readily estimated. If a moraine is but a mile or so in width both borders may be traced in a single traverse by a zigzag course along it; but if several miles in width each border and also the crest may require separate tracing; the moraine is also usually crossed at intervals sufficiently frequent to familiarize one with the variations in expression.

The beach lines of the glacial lakes and to some extent the eskers must be followed at close range to insure correct mapping. Topographic maps are especially useful in giving these linear features their correct position. The same is true of drumlins and kames.

The borders between gravel plains and till plains are usually traced by noting either a change in topography or change in vegetation, supplemented, of course, by such exposures as are to be found.

It is the writer's custom to record data successively as collected in the field without attempt to put them under separate subjects, for much time is ordinarily lost and much inconvenience experienced in making such a separation or grouping while on the trail, especially if it is through fields or brush. At the close of each day an index of the main features observed is entered on the fly-leaf of the notebook, so that when the notebook is filled one has an abstract of the notes contained therein. Then at the close of the field season, the areas and subjects embraced in each notebook are put in a catalog of the notebooks. By this method the writer is able in five minutes' time to find any item entered in any of the 250 notebooks he has filled since he began field work.

On the field maps marginal references are frequently made to the notebooks which contain the principal geologic data, and as much data as can conveniently be placed on the map is entered there as well as in the notebooks.

In the writer's practice mapping in the field is by a system of colors supplemented to some extent by conventions. The colors adopted have been such as to make strong topographic features stand out prominently, while plains are represented in duller colors. Several of the glacialists have come to adopt the same system of colors and this is a great advantage in reading each other's maps. This system has been elaborated sufficiently to bring out drift structure as well as topography. For example, for topography a moraine is given a red color, an outwash gravel plain a brown color, and a till plain a blue color, while for structure a gravelly part of a moraine has a brown color rubbed over the red, while the clayey part has a blue color over the red. One can thus read from the map the change from clayey to gravelly moraine in the absence of notes of any sort on the map.

Inasmuch as flowing wells are of high economic value, the field maps are made to show areas in which they may be obtained. Marl, peat, and other features, when thought to be of commercial value, are indicated on the maps and notes are made as to the value of certain classes of soil for certain products, and so forth. Rock outcrops, glacial striæ, the course of buried channels, and other features of importance are also noted on the map.

It is the writer's habit to enter in the notebooks a brief running description of features noted rather than a mere jotting down of data sufficient to call up the situation. This has been found necessary, not only to render the notebooks intelligible to others, but to insure a correct personal understanding after the lapse of years when the memory can no longer recall the full situation.

Observation needs to be carried along so many lines in the present-day glacial investigations that it is becoming difficult for a beginner to take up the work, and there is a tendency to restrict himself to lines for which he has a special aptitude. One man may be best in mapping moraines and other topographic features,

but not able to satisfactorily interpret differences in the rock constituents of superposed drift sheets. Another may be quick to see differences in rocks but not in topography. Neither of them may be able to use the criteria from vegetation successfully in the absence of natural exposures. It is also found necessary at times to make maps of important topographic features, so that a man with some engineering skill becomes a valuable member of the field force. These facts and the fact that the beginner is encouraged to keep up the work if he realizes he has an aptitude for it, makes it of some consequence in arranging a field party to select men of various tastes and capabilities, especially if a wide range of phenomena are open to study. There is nothing better than field training to develop and broaden the student and this becomes especially fruitful if several men of different aptitudes are thrown into close association. The following is suggested as a good grouping of men of varied tastes in carrying on glacial work.

Make-up of an Effective Field Party.

An effective field party where circumstances permit should comprise, *first,* a man quick to recognize and to accurately map all classes of glacial and glacial-lake features, and also skilled in sketching and in photography. *Second,* a man sufficiently familiar with the rocks and rock formations of the region to work out the directions of ice movement and to discriminate superposed drift sheets of different constitution and age. He should also have ability to recognize differences in weathering and erosion and to properly evaluate the climatic influences. *Third,* a man qualified to make a topographic map of important features or to do other surveying that requires an engineer's training. *Fourth,* an ecologist, or person familiar with plant communities and their relations to various soils, and capable of determining the classes of plants in, and general significance of buried soils between drift sheets so far as climatic conditions are concerned. This person might also collect well records and work out their bearing on the occurrence of successive drifts, and also classify the hydrologic data for publication in water-supply papers.

It is doubtful whether any line of geologic investigation re-

quires more constant exercise of both the observational and the imaginative faculties of the mind than the mapping of glacial features. The great areas involved in the broader elements of the interpretation also require long-continued holding in abeyance of final conclusions. In the writer's experience there are subjects that have been held tentatively for years, some that are still held tentatively after over a quarter century of study, because the field studied is not yet wide enough to clear up their history and relations.

FRANK LEVERETT.

FOSSILS FOR STRATIGRAPHIC PURPOSES.

In a great many geological reports which are chiefly concerned with ore deposits, it becomes necessary to determine the geological age of the sedimentary formations which occur in the vicinity of the deposits. As nearly every geologist realizes, questions relating to the genesis of ore bodies are more or less closely bound up with the geological age of the mineralization and of the enclosing rocks. As all studies of geological age must primarily be based upon the fossil contents of sedimentary rocks, it is often a matter of very great importance to make such determinations, or to have them made by others who are expert in paleontologic work. A collection of fossils must, therefore, be made and sent for careful determination to a paleontologist. The following discussion of the nature and significance of fossils and the precautions to be observed in their collection and shipment may, therefore, justly be regarded as a necessary contribution to the present discussion.

What is a fossil? Fossils or petrifactions are the remains or the natural impressions of animals and plants which have lived at some time previous to the present and are now preserved in stratified rocks. The degree of perfection may vary all the way from an entire elephant preserving not only the skeleton but as well all the soft parts and even the stomach contents, as in the extinct mammoth of the Siberian tundras (which are essentially an ice formation and therefore equivalent to cold storage), to the imprint of a leaf in shale or sandstone. Fossils, however, are

nearly always only parts of once living things, and it naturally follows that such specimens must have very different values in stratigraphy and biology. Then these organic traces, though usually of extinct species, may also be of still living forms. In other words, the present life shades gradually into that of the geologic past, this transition being most gentle among the marine invertebrates and markedly abrupt among the land-inhabiting vertebrates. These decided differences are mainly due to the accident of burial, which is easiest for a shell living on the bottom of the shallow waters of the oceans, while land life must be transported by agitated fresh waters to some area of detrital accumulation. Further, evolution is slower among the marine invertebrates and land plants, and most rapid among the land mammals. Because of these natural conditions, the collector must constantly discriminate which specimens are to be brought into the laboratory; in general, however, it is a good principle to send in too much material rather than too little, because freight is low and return to the field for more specimens usually impracticable.

What is the significance of fossils? Fossils have two values: (1) as "Medals of Creation," showing the course evolution has taken; and (2) as indicators of geologic time or chronology. The second value only is considered in this article and is the one of primary importance, because unless the age of the fossil is known the course of evolution cannot be determined. Fossils without exact stratigraphic occurrence are nowadays almost without value; therefore they must be collected with the greatest care as to their place in the stratified rocks. As all life has constantly changed, the order of superposition of the fossil zones must also be carefully noted and in as much detail as the situation and time will permit. So long as one collects on the same horizon or bed, it does not matter if the specimens from several hundred feet of exposure are mixed into one lot, but it may make a vast amount of difference if the fossils of two or more superposed zones are thrown together. The inexperienced collector, or even sometimes the experienced geologist, does not see the specific differences in the lots of fossils collected from closely

adjacent superposed beds, and for this reason he should be all the more careful to keep the specimens of each zone by themselves. Stratigraphers are as a rule now fully aware of the imperfections in the geologic record, but the rocks of two unrelated formations may rest upon each other with such apparent absolute conformability as to be completely deceptive as to the great depositional break in the section studied. For instance, in the Bear Grass quarries at Louisville, Kentucky, a face of limestone is exposed in which the absolute conformability of the beds can be traced for nearly a mile, and yet within five feet of vertical thickness is found a Middle Siluric coral bed overlain by another coral zone of Middle Devonic time. The parting between these two zones is like that between any two limestone beds, and yet this insignificant line represents a stratigraphic hiatus the equivalent of the last third of Siluric and the first third of Devonic time. Such disconformities are by no means rare, in fact are very common throughout the wide central basin area of North America. Hence an additional reason why the fossils must be gathered zone by zone and kept apart in separate packages, accompanied by labels agreeing with the notes written at the time the collections are made and after the section in hand is understood.

How do fossils occur? Fossils occur in any one of seven different natural conditions, three of which relate to the substance left by the organisms, three to their form, and one to both. (1) The great majority of fossil specimens preserve more or less of the original hard or mineral substance of the individual plant or animal, and to this may have been added in the organic interstices more or less of other mineral substance during the process of fossilization, forming the permineralized fossils. (2) When the original mineral matter is exchanged for another and usually a dissimilar mineral, with the substitute preserving the original microscopic structure of the organism, the process of substitution is called histometabasis. In this condition the woody parts of plants are often preserved and for study purposes are as good as the similar parts of living plants. (3) Plants may be completely

carbonized with the original organic structure more or less completely destroyed during the process. Such fossils have little paleontologic importance but are of great economic value and often are datum planes in stratigraphy and structural geology. The form of organisms with the original substance absent may occur in the rocks as (4) molds, (5) imprints, and (6) natural casts. There is no marked difference between molds and imprints other than that the latter term is applied to impressions of thin substances, as leaves, etc. Natural casts are the counterparts of organisms made by nature by filling the molds of fossils with an uncrystallized substitute; (7) when the replacing material is a crystallized mineral, as calcite, pyrite, and more commonly silica in the form of chalcedony, the replacement is called a pseudomorph. All plants and animals whose original carbonate of lime skeleton was in the form of aragonite (mother of pearl) and silica in the colloidal form (as in the spicules of sponges) are particularly liable to be dissolved away or replaced by other mineral matter.

In Tertiary deposits it is the rule to find the marine shells almost unchanged by the addition of mineral matter, and in general it may be added that the older the organisms are geologically, the more mineralized they are apt to be. Probably 50 per cent. of all fossils still remain in their original calcareous conditon or are but slightly permineralized. This mineralization may take place through the waters percolating in the rocks at any time after the entombment of the fossils or during the time of weathering of the formations, but it is more apt to have occurred during the time of burial when the ground waters of the sea floor were highly charged with carbonic and other acids derived from organic decomposition. For these reasons, the fossil tests of organisms occur in all conditions from the unchanged to complete pseudomorphs in calcite, dolomite, silica, iron pyrite, or even lead, zinc, etc.

Again, the percolating land waters or the ground waters of the sea may have dissolving powers only, and remove all of the organic tests; in this case their former presence is indicated by

cavities in the rocks, the molds and imprints of organisms, more commonly seen in dolomites and sandstones. These molds and imprints are often so wonderfully sharp that the finest artificial casts or squeezes can be made from them. On the other hand, it often occurs that molds, and especially those in dolomites, are covered with a drusy lining of mineral matter, in which case the fossils are nearly always valueless. Even though molds are bulky to collect, nevertheless they should be gathered and as well the casts on the inside of the molds, the original filling of the interior cavities of the organisms. Imprints are more commonly seen in the shales and are the mud impressions of the exterior parts of plants and animals. Even medusæ or jellyfishes, whose bodies are composed of at least 95 per cent. of water, leave at times most wonderfully delicate and detailed imprints.

Where do fossils occur? Fossils may occur in any sedimentary rock laid down by water, either marine or fresh, or by wind, and even wind-carried volcanic ashes may entomb a forest and fauna. They are most easily obtained in undeformed or horizontal strata, and less and less so in the highly tilted and metamorphosed formations. This difference is not due to a greater scarcity of organisms in the bedded rocks of mountain ranges but to the change these rocks have undergone during the process of deformation. Here the fossils are more completely cemented to the matrix and, due to the recrystallization of the rocks, have taken on a secondary structure that not only obliterates the organisms but makes it increasingly more difficult to extract them with the hammer. When the metamorphism is complete, all organic traces are obliterated, but even then the possibility of less changed local areas being discovered still remains. In such places the weathered surfaces should be examined with great care, and when fossils are found, even though they are always very poor, they still have a chronogenetic value. In this way so called Proterozoic rocks around Franklin Furnace, New Jersey, were seen to have the Lower Cambric trilobite *Olenellus thompsoni*.

Fossils are to be especially looked for in the evenly bedded strata of marine origin that are more or less calcareous or

magnesian, and least of all in the red shales and sandstones. In nearly all of the red beds other than red limestones it is the exception to find fossil remains, because the plants and animals were oxidized and dissipated during the process of subaërial sedimentation. It is therefore the green and blue, gray and black, and the subsequently oxidized yellow beds that are apt to hold fossils. However, the red shales and sandstones may also have such fossils as the foot imprints or trails of animals, very rarely the bones of vertebrates, and still less often the imprints of plants or chalcedonized woods. In freshwater deposits fossils are usually very scarce, but subsequent to the Siluric such beds may be replete with plants and vertebrate remains. In general it may be said that freshwater shells have little value in stratigraphy while land plants and more especially vertebrates are most significant as time markers in continental deposits. It is the marine fossils, however, that have the greatest chronogenetic value, because a greater variety of them are being entombed at all times and not intermittently in few species, as is the case with the remains found in continental deposits.

Of all stratified rocks, shales make up more than three fourths, sandstones about 11 per cent., and limestones 9 per cent. It is in the limestones that fossils are nearly always present in abundance but this does not mean that for every foot of limestone nine of the shales and sandstones are barren of organisms. Carbonate of lime is widely disseminated throughout the strata, and in all the calcareous shales there are apt to be fine fossils that will weather out free, and even the calcareous sandstones usually have organisms in some abundance. Then, too, the thick green and blue shale formations often have thin beds of impure limestone or sandstone, and in these bands fossils should be looked for. The shales that are thought to be barren of fossils are largely so because they are usually neglected by paleontologists on account of the poor imprints and the great difficulty in getting them. The day will come when the fossils in the shales will be systematically sought for, although the reward will be small, if we may judge by past experiences, since the soft mud bottoms of the present

marine waters are spoken of as the deserts of the sea. Black shales imply the presence of much carbonaceous material that is almost wholly derived from marsh plants when of freshwater origin, but when of marine derivation, as is commonly the case, the organic matter comes from seaweeds (spore cases are about all that is discernible to the unassisted eye) or small to minute forms of a few peculiar species of floating invertebrates. Such faunas are usually difficult to synchronize, but nevertheless should not be neglected.

Conglomerates may abound in fossils, but here especial care must be exercised in keeping apart the specimens of each pebble, as these may be of very different ages. Then, too, the fossils of the matrix must not be mixed with those of the pebbles for otherwise an imposisble chronogenetic association will result. In this way Lower and Middle Cambric fossils have been found in the Ordovicic (Quebec problem), fine Siluric brachiopods in Jurassic strata (Budleigh-Salterton pebble bed of England), and ammonites in the Tertiary deposits of California. On the other hand, the breccias and intraformational conglomerates have the same species as the binding matrix.

How should fossils be collected? In looking for fossils, do not be in a hurry, as the work of collecting is always a slow process. It is just this that must be impressed upon the areal geologist, for his work demands that he get over the ground quickly. Until he has established his stratigraphic horizons and secured the necessary fossils, he must take plenty of time to look for them, because his stratigraphic sequence is largely dependent upon them. It seems to be the opinion of geologists that paleontologists "scent" the presence of fossils, a conclusion that is wholly erroneous, for they are as a rule discovered only after a great deal of patient hunting.

On any exposure of stratified rocks fossils may occur, and therefore the surface should be scanned for loose specimens. These free fossils are the most desirable because they require the least labor in cleaning and further they show all parts of the individual. The collector should get down on his hands and

knees, collecting the specimens as he crawls over the surface. All of the residual red clays should be searched, as these are often replete with fine free specimens, usually preserved in silica as pseudomorphs.

When fossils are found, trace these to the bed from which they come and while doing so note the occurrence of others still in place. Naturally the best places to find fossils are in the hard protruding ledges of limestone, and all such should be broken in places with the hammer. Sometimes a thin zone will be one mass of fossils, and when weathering has loosened them so that they will fall out freely when hit by the hammer, the easiest way to collect such is to take away a lump from six inches to a foot across. In this connection it should be added that weathered rock yields fossils far more easily than that not so affected.

A ledge of fossils once discovered, the collector should work that bed along the outcrop and leave his results piled on the horizon. He can then proceed to develop in the same manner the successive beds, the amount of work to be devoted to the problem depending upon how much detail he desires to bring out. After the entire exposure is thus worked over, he should then draw and write in his note-book a detailed and measured account of the profile, beginning at the top of the section and fixing in it accurately the various fossiliferous zones. Too much detail about the physical characters of the beds cannot be noted, because it is just this that indicates the environment in which the organisms lived and which the paleontologist wants to know in working out the faunules. The different sections can be numbered and the fossil zones lettered (*1a*, *1b*, *1c*). After the notes are completed, field labels should be written for each lot. These field labels should have on them (1) the geographic location of the section, (2) the number of the bed (*1a*), (3) the page of the notebook referring to the particular zone, (4) the date when the collection was made, and (5) the name of the collector. After the fossils are packed, the lot number (*1a*) should be written on the outside to facilitate easy finding and orienting of the fossils in the laboratory.

Fossils that are not definitely located in the section or collected from talus heaps at the base of a cliff or elsewhere, can as a rule be neglected by the geologist, and especially so if fossils are easily secured in situ, but otherwise these are to be gathered. In this event the field label should definitely state the nature of the loose occurrence.

Fossils of a siliceous nature and partially weathered out of limestone should be gathered in bulk, to be treated in the laboratory with dilute muriatic acid. Material which will bear this treatment is readly tested in the field with a pocket knife; if the blade does not scratch the fossil, but leaves a black mark, it will be well to make the experiment. Of course where the fossils are in cherts or are more or less surrounded with amorphous silica, nothing can be done to free them.

Marls of Mesozoic and Tertiary times often abound in shells, and when these are hard and not like soft chalk the quickest and best way to gather them is to ship a box or barrel of the material. When the marls are soft and mushy, it is advisable to cut out cubes up to a foot across and coat the outside with liquid furniture glue, or, better still, apply strips of cloth dipped in soft plaster of paris and in this way build around the block a stiff supporting jacket.

Ironstone nodules should always be broken to see if they contain fossils; these when present are often the finest of specimens preserved as imprints or molds.

The question is often asked by the geologist, "How many specimens does a paleontologist want?" and the answer invariably is, "As many as he can get." However, there are practical limitations to the work of the geologist, and he must be the judge of the amount to be gathered. It is not so much a quantity of specimens as it is of species that a stratigrapher desires, because it is known that different forms have very different chronogenetic values. As a rule, the more abundant a species, the less its stratigraphic significance. I recall how disappointed one of our leading geologists was, after handing me a lot of fine specimens of a certain brachiopod (*Atrypa reticularis*), with the question,

"These indicate Cambrian, do they not?" This species, however, never occurs there nor in the Ordovicic, but is found throughout the entire Siluric and Devonic periods. When I told him this he realized that some one was hopelessly wrong. Another illustration of the Paleontological autocrat! What is wanted is a variety of forms, and it is the combination of species in a faunule that is significant. When fossils are abundant and small, as they so commonly are in marine faunas, the geologist can as a rule readily gather enough in an hour's work to enable the paleontologist to make a satisfactory time diagnosis. Regarding fossils in continental deposits, the difficulties in getting them are great because they are few and far between, and when present the shells are usually almost valueless as time markers, while the bones require a special training to take them out of the sediments. If leaves or fishes are present, these should be gathered as indicated for marine invertebrates. However, every fossil has some chronogenetic value and the best advice to the geologist is that his salvation lies in collecting what he sees and can get.

Finally, do not trim the rock too close to the specimen, because often the essential parts of the fossils are thus lost.

As regards packing, all the invertebrate and plant specimens should be so wrapped in old newspapers that they will not rub on one another. When the invertebrates are numerous and small, a number anywhere up to two dozen can be rolled up in a package, and these packages should again be wrapped into a larger bundle, in which case but a single field label is necessary inside the larger package. Each large specimen with its field label, should be wrapped independently and with plenty of paper to prevent rubbing in the box during transit. Thin slabs should be set vertically in the box, for otherwise they will be badly broken before they arrive in the laboratory.

CHARLES SCHUCHERT.

CONTACT ZONES.

DISCUSSION OF PAPER BY W. L. UGLOW.

Sir: Mr. Uglow's review of the conclusions advanced by one geologist and another in explanation of the interesting contact

zones, is evidently based on quite extensive reading and upon experience in the field. The author has obviously given the subject much thought and has endeavored to summarize under brief and concise heads the points which have seemed to him to be significant. The paper will serve a good purpose if it excites discussion and brings under the test of critical examination not alone the views with which the author differs, but more especially those with which he is in sympathy. A reader cannot always escape the impression that Mr. Uglow's sympathies are so strong as to make him hardly fair to opposing views, and to lead him to overlook the more or less serious difficulties in the way of the explanations which he himself advocates. In instances, especially in the citations of papers from the writer fundamentally important matters have sometimes been passed over or have escaped attention, so much so as to lead one to regret the very faulty impression gained by Mr. Uglow from their reading.

No review of the explanations advanced for contact zones can fairly be considered complete, which omits all reference to the most thorough and painstaking investigation of them which has yet been completed and published. This is the work of Dr. Victor Goldschmidt upon the zones near Christiania, Norway. It is appreciatively reviewed in ECONOMIC GEOLOGY for October–November, 1911, pp. 707–708, by Mr. Ransome, but the book itself contains such a wealth of analyses and carefully thought-out conclusions as to deserve study in the original. Dr. Goldschmidt wrote, undoubtedly, under the influence of the views and sweeping statements of Mr. Paul Brun, regarding the absence of magmatic waters in molten rocks. Mr. Brun even states, that as the result of his investigations water must hereafter disappear as a factor in vulcanism. Whether the demonstration by Messrs. Day and Shepherd of rather abundant water in the lavas of Kilauea would lead Dr. Goldschmidt to modify his views is a fair question. That, however, silica and iron are contributed by the intrusive to the andradite-amphibole zones, Dr. Goldschmidt fully concludes; but that grossularite and pyroxene may result from marly limestones, without additions and in the earliest stages of

intrusion, he also believes. The emissions of silica and iron appeared at a later stage, and with them came forth also sulphur, fluorine, chlorine and the alkalies, together with various metals. These views are shared by Professor Broegger, under whom Dr. Goldschmidt's dissertation was prepared for his doctor's degree, and with whom the writer has also discussed them, while visiting some of the Norwegian zones under Professor Broegger's guidance. It is hardly correct to class Professor Broegger along with Professors Zirkel and Rosenbusch as an advocate solely of the recrystallization hypothesis, as appears on pp. 23 and 24 of Mr. Uglow's review, under the first hypothesis. Probably in the light of new and significant evidence even the two other famous students of rocks might have modified old views. The older studies of contacts were more often of the andalusite hornfels and related types than of the garnet zones. So far as the garnets are concerned, so long as every one inferred the presence of only grossularite, the lime-alumina variety, the same conclusions applied to it. Silica and alumina are often found in limestones in amounts sufficient to merit attention in these respects, but now that we know andradite, the lime-iron garnet, to be much more abundant, the whole situation is changed. Until its presence and amount were appreciated, the writer, like everyone else, trusted to the recrystallization of sediments, and was especially influenced thereto by Alfred Harker's paper on the Shap Granite of Westmoreland. The effects produced by this granite upon the amygdaloidal fillings of a basalt showed a migration of material not to exceed 0.05 in. The rich soda rocks, however, which are often called adinole and which are found around some European intrusives, had long ago led several continental petrographers to infer the introduction of at least this alkali.

Under hypothesis 2 on p. 24 of the review, Mr. Uglow sums up in a few lines what he considers to be the views which are based on contributions from the intrusive and attributes them especially to the writer. With a subsequent reservation in favor of such silica, alumina and iron oxide as might be in the original limestone as impurities, the supporters of this view are at first cited as introducing everything but calcium carbonate from the

intrusive. To quote, referring to myself, "He maintains that the intrusive emits great quantities of vapors containing SiO_2, Al_2O_3, Fe_2O_3, FeO, MgO, H_2O as well as metallic sulphides and oxides." I certainly did not advocate the introduction of MgO in the citation[1] given by Mr. Uglow, and should in general be quite strongly opposed to its derivation in this way. A renewed reading of the paper seems to give slight ground for these sweeping assertions, but to show quite guarded statements, chiefly to the effect that the available analyses certainly do not reveal in the limestones the required amounts of silica and the iron oxides for the zones, and to raise doubt about the alumina. A similar doubt about alumina apparently arose in Mr. Uglow's mind about alumina after his review appeared in print, since in the reprint kindly sent the writer, paragraph No. 3 on p. 46, viz., "3; Al_2O_3 is practically unknown in igneous emanations" is crossed out. Feldspathic pegmatites and cryolite are of course good evidence that aluminous contributions do come from igneous masses.

No one can doubt for a moment that to the extent to which the original limestones contained silica, alumina and the iron oxides these components might be expected to enter the resulting contact minerals but the question whether they are there in sufficient quantity is a serious and vital one. To this point we may return after noting one or two minor points in the tabulated and numbered arguments in Mr. Uglow's review.

Under no. 2, p. 28, referring to Professor Crosby's paper on Washington Camp, Ariz., grossularite is stated to occur only along the part of the contact which coincides with the impure layers of limestone. Mr. Uglow could not have known that a later and unpublished analysis has shown the garnet to be largely andradite. It would therefore be necessary to demonstrate an extraordinary percentage of iron oxides in the impure layers, a condition which is highly improbable. Opposite no. 4 it might have been stated that the special beds which became silicates might have been more permeable to emissions than those on either side

[1] J. F. Kemp, Contact Deposits, in "Types of Ore-deposits," published by The Mining and Scientific Press, San Francisco, 1911.

of them. This possibility is not a negligible one. It was an old subject of discussion between the writer and Dr. W. L. Austin as referred to under no. 19. Under no. 5 the idea is brought up that the silicates are of irregular distribution along the contacts of intrusives and limestones, and that if they were due to emissions from the intrusive they should appear in an unbroken fringe. There does not seem, however, to be any sound objection to the belief that emissions from the inner part of an outwardly chilled and solidified intrusive favor local channels rather than uniform general emergence. In further reply to no. 5 my own observations as well as those of others have not led to the conclusion that the contact silicates which we have observed had any connection with more impure layers. I could find no such evidence at San José. On the contrary the bodies of silicates ceased and apparently pure limestone or marble succeeded them farther out.

With reference to no. 6, I find little or nothing in the original citation to justify the paragraph. Mr. Uglow's reading of the White Knob paper must have been very hasty. The silicates are found in a number of pipes, believed to be entirely in the igneous mass and while near are not next the limestone within the portions open to observation. From eight or ten outcrops the pipes appeared to have converged in depth to three or four, which probably still further unite lower down. These pipes of iron-lime silicates within an eruptive are not easy to understand, but they give slight support to the ideas of the recrystallization of limestone, whatever other views may be held of them.

Under no. 8, because the ores are usually (not invariably, it should be remarked) later than the silicates, I can see no objection to their formation by direct contribution from the igneous mass. No. 10 makes one wonder why the obvious is stated with such solemnity. It would indeed be foolish to derive the carbonaceous material, the bands of chert and the dolomite beds of any limestone series from a near or a remote intrusive. Surely no one has as yet attempted it, least of all Mr. Guenther and myself, to whom such views are apparently

attributed. To no. 11 we may reply that we all know there are impure and shaly limestones in Nature. In reply to no. 12 one may slightly paraphrase the original into "*why* should the quartz enclose kernels of crystalline limestone" if "it *was* the result of recrystallization of chert already in the limestone?" That is why should not siliceous hot waters produce a network of quartz veinlets in limestone just as well as the recrystallization of chert? Mr. Lindgren could best decide in connection with no. 13, whether the limestone at Morenci, which has been changed to silicates, originally contained the necessary impurities to yield the silicates. Apparently he did not think so when writing his monograph. In connection with no. 14 there seems nothing in the facts stated to oppose the formation of silicates by gaseous and liquid contributions from the intrusive at several stages of cooling. No. 15 is crossed out in the reprint. Under 16 it would seem indefensible to state that the alteration of limestone to iron-garnet and diopside rock is the natural recrystallization of this sediment. Limestones of a composition to give this result are extraordinarily rare, if indeed they ever occur. Mr. Lindgren's figures and claims briefly cited under no. 17 are justifiable because the evidence shows that the limestone did not contain the necessary components of the silicates, other than lime and magnesia, while the eruptive did have them. No. 18 in this condensed form gives a very faulty impression. The San José paper of the writer is an endeavor to state with accuracy a series of observations, believed to be correct. There was no disposition to be a partisan of any particular views but to interpret certain phenomena in the most reasonable way. My predispositions were all in favor of the recrystallization of impure limestones for the formation of lime-silicate zones. There are thousands of feet of limestone at San José, but the contact zones are almost all developed around separate masses torn off and included in a huge laccolith. It would be surprising indeed if such a great section did not contain some layers more earthy than others. They were however rather notably few than notably many. There was no evidence that the siliceous beds gave rise to the zones but quite the reverse. After

crossing and recrossing the section many times, the writer's conclusion was that the zones of silicates could not reasonably be explained by the re-crystallization of the limestones. This instance, like no. 9 on p. 35, of the points considered favorable to direct contribution, illustrates the impossibility of getting at the large bearings of a case in a few disjointed sentences.

Under no. 9 we find, "Kemp states that the recrystallization of a limestone would require the production of cavities, which in reality are not found. The silicate rock is a fairly dense and solid variety." Mr. Uglow comments that the great pressure under which the recrystallization takes place would eliminate cavities. But the real point is that Professor Barrell, in one of the ablest papers called forth by the study of contact phenomena, showed that the recrystallization as grossularite would leave forty odd per cent. by volume as cavities. In reply while not denying the presence of vugs and cavities the writer made the point that they were too few for re-crystallization. They are also too many to have been left in rock under such pressure as should have closed them up.

Under no. 6, p. 34, in citing Mr. George Smith's paper on the Chillagoe zones, as well as in the introductory hypotheses, it would be fair to state that Mr. Smith believed the garnet rock to be a separate and distinct intrusive, and not the product of contact action at all. Under no. 21, p. 36, it is rash to speak so confidently of grossularite without analyses. With reference to no. 11, p. 37, of the points favorable to direct contribution, the vast development of silica in one form or another near the Cumberland-Ely mine of the Robinson District, Nev., first described by Professor Lawson, may be later than the silicates, but the writer did not get that impression in walking over the hill for a short study of it. There are occasional masses of garnet but they are rather few. They are intimately associated with the siliceous rock. They all seemed to go along together. The case reminded one of the silicified limestones which are sometimes described, in which even fossils may be preserved, but in which lime-silicates fail. Regarding my own early reference in 1894, of garnet and colorless pyroxene to dynamic metamorphism in a case in the

Adirondacks I was younger and less experienced then. After going again over the best of the zones, three years ago, I think for this one I made a mistake in 1894. The formation of gold in association with bismuthinite and bismuth telluride by the recrystallization of a sediment as supported under no. 27, p. 39, will raise a query in the minds of some readers. The combination is an extraordinary one for unassisted sediments.

To the last paragraph, no. 30, p. 44, the objection cited from Professor Lawson that since garnet zones are many and ore-bearing garnet zones are few, therefore contributions from the eruptive are improbable, we can only say that the useful metals other than iron are rare in nature. Apparently all intrusives do not contain them. Many times igneous rocks do not yield them. This peculiarity holds true of quartz veins as well. The greatest quartz vein known to the writer is in southeastern Connecticut, and it has many smaller associates in the neighboring parts of Rhode Island. The quartz veins are there for a great mining industry, but the gold and other customary metals fail. We do not know why, unless it is because the neighboring granites did not contain them.

These minor matters are however of less moment than certain large considerations which deserve more serious attention. In the views supported by Mr. Uglow, the lack of silica, alumina and iron in the original or unaltered limestones which others have believed were transformed in situ by new contributions into the zones of silicates, is met by the suggestion that the heat effects of the intrusive presumably through the agency of magmatic waters have removed the lime and presumably the magnesia, to so great an extent as to leave insoluble residues, comparable in gross composition to the zones of silicates. The progressive recrystallization of the residues under the heat of the igneous mass has then given rise to the garnet, wollastonite, diopside, epidote, amphibole, etc. The great masses of magnetite and specular hematite which we so often meet in the zones, are indeed attributed to introductions from the eruptive, but the introduction of silica, alumina and the iron oxides of the silicates is opposed. The loss of volume from the removal of the calcium and magnesium

carbonates and of all the carbonic acid once combined with the alkaline earths which are now locked up in the lime-silicates, is compensated by assuming compression from the intrusive or by expansion of the wall rock from accessions of heat. The suggestion finds one of its chief supports in the supposed parallelism or identity of ratios as among the comparatively small amounts of silica, alumina and iron oxides of the unaltered limestone and of the same components in the garnet zones. Mr. Uglow dismisses as of little or no value the analyses made by the writer and others of such samples of limestone as we believed, from field relations, represented the original limestone, but has great respect for analyses of average samples which represent much greater cross-sections.

Certain weak points in the ratios given in Mr. Uglow's article have already been remarked by Dr. C. A. Stewart but there is a fundamental one which seems to the writer unanswerable. If the ratios have any significance we are obliged to believe in the solution of calcium and magnesium carbonates and their removal in vast quantity by waters which all our experience leads us to believe were alkaline, and yet without the solution and removal of any silica, alumina and iron oxides at the same time. These waters became heavily carbonated and yet they can have had no effect upon silica, largely in its most soluble form of chert. Some of the generally trusted chemical views of the Lake Superior geologists upon the rearrangements of silica and iron oxides in the cherty iron carbonates of Michigan and Minnesota must be very faulty, if Mr. Uglow's ratios are to be trusted as casting light on the problem. If the calcium and magnesium carbonates were removed, the silica and the ferrous iron surely went with them and if they did we may throw out the evidence of the ratios, since the old proportions were destroyed.

We also have this further difficulty. The zones of silicates are still high in lime and magnesia. Garnets contain between 30 and 40 per cent. CaO; vesuvianite the same; diopside between 40 and 50 per cent. CaO and MgO; wollastonite 40 per cent. CaO; and other common silicates similar percentages. A pure limestone has only 56 CaO, and a pure dolomite about 52 CaO and MgO.

Thus while solution by the magmatic waters is removing something like 10 to 20 of the 40 to 50 or more per cents (that is one fifth to two fifths) of the CaO and MgO in the limestones, it must at the same time increase the silica, alumina or iron oxides up to three to ten times their original amounts. No such process seems conceivable. We cannot explain the production of the zones of silicates of known composition from the limestones of composition known within small possible variations, without the introduction from an outside source of the silica, alumina and iron oxides.

We do not know, of course, at just what stage in consolidation the emissions are given off, but we cannot speak of magmatic waters in the liquid state or even of undissociated steam, unless the intrusive had solidified with a very thick outer shell, which where water was present, had cooled below the boiling point for the physical conditions prevailing. Its center may or may not have still been molten. Under these circumstances it seems to be impossible that the advance of such bodies of intrusives as we find associated with garnet zones could compress the imagined residual zones, irregular and localized as they must have been, so as to take up such a shrinkage as would have been, for example, produced in reducing 300 ft. to 80 or 90 ft. On the contrary much the more reasonable view is to believe that the intrusive in cooling and crystallizing, itself shrinks in volume and reduces pressure rather than increases it. The re-advance of the still fluid core of a partially congealed intrusive is more likely to be shown in dikes through the shell or in outbreaks elsewhere. In actual cases the writer has never felt it necessary upon the basis of observation to consider the re-advance of an intrusive essential to the explanation of the phenomena or suggested by them. We may, however, raise the question whether as a matter of fact, intrusives do bulge outward where garnet zones appear and retreat where only crystalline limestone forms the contact.

Since writing the previous portion of this discussion, all of which has necessarily been prepared while in the country and without access to original papers, other than the reprint kindly sent by Mr. Uglow, the writer has had the great privilege of

several days in the field with Professor Leith and of an opportunity to talk over some of these questions with him, in whose laboratory Mr. Uglow was working when the review was prepared. I learn that I had formed an erroneous conception of the process and of what was meant on p. 223 of Mr. Uglow's paper by the expression "advance of the batholith." It is the original entering advance which is meant; not a re-advance after cooling and consolidation had progressed as stated in the preceding paragraph. Yet as against any conception of a readvance as a cause of compression, I will let the paragraph stand for what it is worth. I have always imagined the intrusive entering the sediments, making a way for itself by any of the commonly advocated processes such as thrusting aside, hoisting aloft, in-fusion and digestion, or overhead stoping. The zones as ordinarily seen are not products of assimilation, because the contacts between intrusive and walls are sharp and clean-cut. I have always imagined the batholith as having come to rest, and as then in its cooling stages producing the effects. When an advance was mentioned I inferred it to be a new advance. If, however, the zones or their first stages are imagined to be formed while the intrusive is still molten, plastic, and capable by fluid or viscous flow of following up the removal of carbon dioxide because of the great compression necessarily prevailing, cavities left by this gas in its escape would be closed up and reduction of volume might ensue. Whatever is true of carbon dioxide also holds good for the escape of water from kaolin or other hydrated minerals. At the exalted temperatures required to break up the calcium carbonate, water would certainly become highly heated vapor or even dissociated hydrogen or oxygen, and no way seems provided for the removal of lime or magnesia until a much later stage in cooling, when, contractions and loss of pressure having ensued, solvent water is a possibility. Lime and magnesia cannot, of course, be volatilized.

So far as garnet is concerned, it would seem to be necessary to infer its formation at temperatures less than its fusing point. Someone has shown (writing without access to works of reference, the citation cannot be given from memory), that garnet on being melted under ordinary surface conditions does not crystal-

lize again as garnet, but as a mixture of other silicates. While presumably the fusing point of garnet rises with the pressure, its behavior may afford us a superior limit of temperature at which the metamorphic reactions take place.

Mr. Uglow has given a summary of conclusions reached by Professor Ingersoll, of the department of physics at the University of Wisconsin, which are of very great interest and which are now separately published and generally available. Assuming a temperature of 1000° C. for the fused intrusive, lying against its walls, Professor Ingersoll calculates the time required by the outwardly advancing heat to bring to various temperatures the walls at specified distances from the intrusive. The diagram on p. 230 assumes an intrusive at 1000° C. in contact with limestone at 0° C. The thin layer of limestone immediately adjacent to the intrusive would soon reach nearly or quite 1000° C. but after 100 years Professor Ingersoll's curves show that the contact itself would be 450° C.; the limestone about 5 meters out, 400° C.; about 25 meters out, 300° C.; about 50 meters out, 200° C. and 100 meters out, 110° C. Since no rock beneath the surface would have an initial temperature as low as 0° C. we may add from 50 to 100 degrees to the above figures. After 1600 years the temperature of the contact has fallen to 350° C. (plus 50° to 100°); and after 3600 years it is about 60 degrees less. After 10,000 years the actual contact is about 170 degrees (plus 50° to 100°). Thus we see that heat radiates very slowly and that except for a very narrow border zone, presumably of only a few feet, during the years immediately following the entrance of the intrusive, we have to deal even after a century with temperatures of 500°–550° C. at the contact (i. e., 450° + 50° or 100°), which rapidly diminish outwardly. Even at points just outside the surface of contact, heated waters, at the pressures prevailing, could physically exist a century or so after the entrance of the intrusive; and from the slow diffusion of heat, were dissociated hydrogen and oxygen to be emitted by the igneous mass immediately on its entrance, they could re-combine very near the surface of contact.

Mr. Uglow gives as good an idea of the physical conditions of the dissociation of CaO, CO_2 as the data of recorded physical

experiment admit. In the presence of SiO_2, Al_2O_3 and Fe_2O_3, these seem to be met by the conditions of intrusion. That is, within the ranges of temperatures shown by Professor Ingersoll's curves, it seems possible for more or less complex lime-silicates to be produced with the eviction of the CO_2 and the H_2O. But as to the calcination of pure CaO, CO_2 there are certain features of the contacts as exposed to observation which furnish a check on conclusions. One of the peculiarities of the contact phenomena is the irregular distribution of the masses of lime-silicates. Often next the intrusive and for long distances we find only crystalline limestone as the result of contact-metamorphism. In less extensive development we then find the scattered zones of the silicates. Some have explained the marble as due to relatively pure original limestones, from which only a re-crystallized product has been produced. The silicates are ascribed to impure bands in the limestones. Others have explained the lime-silicates as largely due to local contributions from the intrusive, which failed where marble alone appears. The marble is, however, so abundant and so extended as to convince an observer that practically no dissociation of CaO, CO_2 took place where it is seen. So preponderating is this relationship as to justify the question whether any CO_2 is freed except by the combination of SiO_2, with or without Al_2O_3 and Fe_2O_3, with the CaO and MgO of their respective carbonates. The same temperatures must have prevailed all along the contact. We are forced to come back to the early conceptions of the recrystallization of impure limestones where there is reason to think the original limestone contained sufficient impurities and was of the proper chemical composition; or to adopt one involving contributions of silica, ferric oxide, and probably also alumina from the intrusive, where our analyses show that these components were not in the requisite amounts in the original limestone.

There are phenomena in the zones which cannot be explained by recrystallization alone. The writer has still a specimen from San José showing a vein of vesuvianite about an inch wide, crossing white marble. Some kind of vapors or solutions went along an original crack and changed the bordering limestone to

vesuvianite, whose well-bounded crystals project from the vein filling into the bordering rock.

In the very interesting paper of Leith and Harder upon the Iron Springs contacts of southwestern Utah, the production of the residual products is admitted to have caused a shrinkage in the bordering limestone from 300 ft. to 80 or 90 ft. and yet the surrounding strata show no crumpling or crowding but as described by Mr. Uglow under No. 30, pp. 40 and 41 of his paper, continue with only an outward tilt from the laccolith, right up to the zones of silicates. If we see difficulties in believing that pressure from the intrusive compacted them, these relations are a grave objection to the hypothesis supported by Mr. Uglow and a strong point in favor of contributions from the intrusive, which make the assumption of compacting unnecessary. In the Iron Springs case the assumption, moreover, that magmatic waters or similar vehicles have brought from the intrusive many millions of tons of iron oxides and yet no silica, the most abundant component of the igneous rock, the most natural of all things to be given out by it; and the most natural to be trapped by the limestone in bordering silicates, seems open to grave objection.

Mr. Uglow in closing admits variety in the phenomena of contact zones and suspects that the things reported which are contrary to his favorite hypothesis are due to observations biased by the observers' personal equations. It would be a serious indictment of observers, if this were not true.

J. F. KEMP.

THE MICROSTRUCTURE OF TITANIFEROUS MAGNETITES.

DISCUSSION OF PAPER BY J. T. SINGEWALD, JR.

Sir: The paper by Joseph T. Singewald, Jr., on "The Microstructure of Titaniferous Magnetites" deals with a subject that has many claims to scientific and economic interest and bears evidence of a wider research than has been attempted hitherto with similar methods.

The use of polished surfaces etched with hydrochloric is peculiarly effective in bringing out the textural and mineralogical features of these ores as I found some time ago in reference to the Adirondack occurrences. By this method, the presence of ilmenite in discrete particles, practically equidimensional with the associated magnetite, was demonstrated for many of the deposits beyond all doubt. That the titanium existed in the form of ilmenite, however, was considered quite probable by previous writers on the Adirondack, as noted for instance in Professor Kemp's paper in the 19th Annual Report of the U. S. Geological Survey. It is due to this feature, of course, that a measure of success has attended efforts to beneficiate the ores by magnetic separation. The most definite experiments along that line that have come to my knowledge were carried out a few years since at Mineville on samples from the Lake Sanford district.

It was found that in a large way and without excessive crushing, the titanium content could be reduced to 6 per cent. or lower (equivalent to about 10 per cent. TiO_2). The iron in the concentrates exceeded 60 per cent., with low phosphorus and sulphur, making them a very desirable material for the blast furnace from every standpoint except that of titanium. Inasmuch as some of the so-called non-titaniferous magnetites carry appreciable amounts of that element, apparently without material detriment to their metallurgical value, it would seem likely that concentrates of that character could be used at least in mixtures with other ores. The effects of the separation are more evident in the tailings than in the concentrate, as the former showed about 32 per cent. TiO_2 with 42.84 per cent. Fe, whereas the average crude material from the better deposits carries about 15 per cent. TiO_2 and 55 per cent. Fe. By recrushing the concentrates so as to pass a 16-mesh screen and separating with a hand magnet, a material was screened that contained only 5.25 per cent. TiO_2 and 63 per cent. Fe. This seems to represent about the extreme limit to which separation of the magnetite and ilmenite can be carried in the ores from the Lake Sanford district. The inability to effect a cleaner separation can be ascribed probably to the presence

of about that equivalent of titanium in the magnetite molecule itself, an inference that is further strengthened by microscopic study.

The adaptability of the magnetites to this treatment varies widely, even in the limits of a single district, which is equivalent to saying that in some deposits, the titanium has had greater opportunity to separate in the form of ilmenite than in others. Slow uninterrupted cooling seems to be one of the essentials for the development of ilmenite in association with a low-titanium magnetite, and the cleanest separation in the Adirondack localities, at least, is found in the coarse crystalline ores which have the anorthosite, a nearly pure labradorite rock of extremely coarse texture, as walls. This type is limited practically to the Lake Sanford district in the heart of the Adirondacks. Elsewhere, the magnetites occur in true gabbros or norites which appear to be mostly small intrusions in the form of dikes and bosses of later age than the anorthosite; in such surroundings, they have usually finer grain, more impurities in the way of sulphides and silicates, and less of the titanium segregated as ilmenite. Certain specimens in fact, when polished and etched, reveal nothing but a uniform metallic-looking base that cannot be differentiated under the high powers of the microscope or with the aid of the magnet.

The titaniferous magnetites contain practically all of the minerals of the wall rocks as mechanical inclusions, such as plagioclase, pyroxene, hornblende, biotite, olivine garnet, spinel, quartz and iron suphides. Some are very sulphurous. An interesting ingredient of the larger ore bodies on Lake Sanford is native copper which occurs in disseminated grains and scales embedded in the matrix. Its presence is traceable probably to original grains of chalcopyrite, although the two were not found in association. With the use of polished surfaces, a fair estimate of the relative richness of the magnetites is readily obtainable, as the silicates stand out prominently from the metallic minerals; in the rough specimens, there is more difficulty in distinguishing the two classes.

An apparently anomalous occurrence of titaniferous magnetite for the Adirondacks, but which seems to form a connecting link

with some of the so-called, but not actually, non-titaniferous magnetites in the granite and syenite gneisses, is found at Port Leyden on the west side. A lens of fine-grained pyritic magnetite which has been explored in a small way exists in a microperthite-quartz gneiss that in its general aspects is identical with the quartz syenite gneisses that contain many of the low-titanium ores. The magnetite is mixed with feldspar and quartz of the same nature as those of the country. Whether it represents an intrusion from some underlying basic magma or a segregation in place of the syenitic rock could not be definitely decided from the field evidence, although these rather pointed to the latter method of origin as the contact seems to be one of gradation, characteristic of the ores in the anorthosite-gabbro series, as well as for some of those in the gneisses proper. The ore on analysis showed about 9 per cent. TiO_2, or roughly, half the average quantity of the ordinary titaniferous ores of the region.

D. H. NEWLAND.

REVIEWS

A Manual of Petrology. By F P. MENNELL, F.G.S. Chapman & Hall, Ltd., Covent Garden, W. C., London, 1913. 255 pp., 124 figs. Price 7/6 net.

This work is founded on "An Introduction to Petrology," published in 1909, by the same author, who considers the new title justified by the changes in treatment and additions to the earlier work. In his preface Mr. Mennell, who has spent over ten years in field work in South Africa, rather naïvely remarks that, "For the most part this book was written at too great a distance from the center of scientific thought to owe much to outside influences save as conveyed through books." He purposes the book to be useful to the student as well as to the working geologist.

The first two chapters treat very briefly of the physical properties of minerals from the viewpoint of their determination, while Chapter 3 discusses "phenomena in polarized light" in such an elementary way as to be almost valueless. The next four chapters describe the chief rock forming, accessory and secondary minerals. These descriptions contain many of the more important diagnostics, although they are deficient in good optical data so needful to the working petrologist. No quantitative idea of the birefringence and only the mean indices of refraction are given. Even these are sometimes inaccurately stated, as for instance, that muscovite has exactly the same index as quartz and that biotite has an index of 1.5.

Igneous rocks, their study, classification, processes of crystallization and structure is the subject of the next chapter in which the use of the chemical character and particularly the silica content is emphasized as a basis of classification, and the processes of crystallization and their resultant effect in producing the various rock structures are outlined. The variation of igneous rocks is thought to be explained, not so much by processes of differentiation as ordinarily understood, but rather "from what is often termed refusion, that is to say, from the melting down of all classes of preexisting rocks." From study of the various rocks of Rhodesia, the average silica content of the earth's crust is thought to be approximately 69.45, or practically that of a granite. From this the author argues further for the assimilation of heterogeneous material as one of the important factors in the production of the various rocks,

emphasizing the processes of "selective absorption" and "liquation through fusion."

The commoner igneous, sedimentary, and metamorphic rocks are briefly described and the subject of metamorphism is discussed in a very superficial way. Succeeding chapters deal with "the chemistry of rocks" with especial reference to the average composition and to the occurrence of each of the more important earth-forming elements, "radioactivity" and its geological significance and finally, hints on the "collection and preparation of material."

The petrology is elementary and incomplete and lacks philosophical perspective. However, it contains some useful information particularly as sidelights on the geology and petrology of South Africa. Neither the improvement over the earlier work nor the character of the book seem to warrant the change of title from an introduction to a manual of petrology.

J. FRED. HUNTER.

The Underground Water Resources of the Coastal Plain Province of Virginia. By SAMUEL SANFORD. Bul. No. V, Virginia Geological Survey, 1913. Pp. 361, 1 plate, 8 text figures.

This bulletin, which was prepared in coöperation with the United States Geological Survey by a former member of the federal survey staff, has the general scope and purpose of the water-supply papers of the federal survey that are based on underground water investigations in specific areas. It is a comprehensive report on the waters of the coastal plain formations, ranging from Lower Cretaceous to Pleistocene, and of the underlying crystalline rocks, in an area of 9,500 square miles known as tidewater Virginia. As summarized by the author, it "covers the occurrence and character of both shallow and deep waters; the geological relations of water beds; extent of artesian horizons and areas in which flowing wells can be had; methods and costs of developing underground water supplies; special adaptability of waters for domestic or medicinal use, and their application in agricultural and other industries; the relation of well and spring waters to the public health with particular reference to water-borne diseases; in short, the report is intended to answer those questions relating to underground water that would be most likely to occur to any one interested in the subject, whether resident, homeseeker, or promoter of industrial enterprises." The accompanying map shows, (1) the limits of the area in which deep wells yield adequate supplies of unmineralized water, (2) the distribution of chlorine in the underground waters, and (3) the limits of the areas in which flowing wells can be obtained from the Chesapeake sands, the Pamunkey sands, and the Potomac sands, respectively.

In many places there are bodies of underground water perched on impervious clay beds below which there may be dry sand. Holes bored through the clay may drain the perched water and by this method certain wet lands can be reclaimed.

Fluctuations in artesian head are common in tidewater Virginia, and are caused by fluctuations of the river levels, by the rise and fall of tides, and by changes in atmospheric pressure.

In the principal artesian beds there is a progressive increase in the mineralization of the water toward the southeast, which is the general direction in which the artesian water moves. The increase in bicarbonates is the most noteworthy feature. The author explains that the water in its underground course takes up bicarbonates and, if originally hard, becomes soft by losing much of the lime which it contained. He states that soft sodic-bicarbonated waters are found also in other parts of the Coastal Plain. It is interesting in this connection to note that, according to recent investigations of the United States Geological Survey, this rather uncommon type of water is characteristic of certain Cretaceous sandstones in as widely separated states as Minnesota, South Dakota, and New Mexico, and in some places affords a reliable criterion for correlation of buried formations. The author states that bicarbonated waters stimulate the growth of algae, its difference from most underground water in this respect being striking. A heavy growth of "green moss" accumulates in troughs and about the mouths of flowing wells that yield such water.

O. E. MEINZER.

SCIENTIFIC NOTES AND NEWS

THE COMMITTEE OF MANAGEMENT of the International Engineering Congress, 1915, announces that Col. Geo. W. Goethals, chairman of the Isthmian Canal Commission and Chief Engineer of the Panama Canal, has accepted the honorary presidency of the congress and will preside in person over the general sessions to be held in San Francisco, September 20–25, 1915.

THE BUREAU OF MINES of the Department of the Interior have recently published the following papers of interest to the readers of ECONOMIC GEOLOGY: Technical Paper 42, "The Prevention of Waste of Oil and Gas from Flowing Wells in California, with a Discussion of Special Methods Used by J. M. Pollard, by Ralph Arnold, and V. R. Garfias." Bulletin 64, "The Titaniferous Iron Ores in the United States, their Composition and Economic Value," by Joseph T. Singewald, Jr.

THE FOLLOWING ITEMS from the Bureau of Science of the Philippine Islands will serve in some measure to acquaint the readers of this journal with the activities of the Philippine Bureau:

Dr. Tempest Anderson, the well-known traveler and vulcanologist, of York, England, spent the months of May, June, and July in the Philippine Islands, where he made studies of Philippine volcanoes. He lectured before the Bureau of Science Club and also before the Cosmos Club of Manila, which is an organization made up of scientific men from the various bureaus of the government.

Professor Curtis, of the Geological Department of Harvard University, recently visited the Taal volcano.

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

Mr. Paul R. Fanning, mining engineer in the Division of Mines of the Philippine Bureau of Science, was sent as representative of the bureau to the Twelfth International Geological Congress in Toronto. Several members of the staff of the Division of Mines sent papers to be read at the congress.

The Division of Mines of the Philippines has ready for the press: (1) The Stratigraphy and Fossil Invertebrate Fauna of the Philippines, by Warren D. Smith; (2) Seismic Disturbances and Their Relation to the Geologic Structure of the Philippines, by Father Masó, of the Philippine Weather Bureau, and Warren D. Smith, of the Bureau of Science; (3) The Geology of the Tayabas Oil Field, by Wallace E. Pratt and Warren D. Smith; (4) The Geology of the Bulucan and Adjacent Iron Districts, by F. A. Dalburg and Wallace E. Pratt.

F. T. Eddingfield, mining engineer, Division of Mines, Bureau of Science, recently accompanied the Secretary of the Interior on a trip around the island of Luzon, touching at one or two of the islands in the Babuyanes group, and also around the island of Mindoro, from which he brought back some valuable notes about the geology of little known parts of the archipelago.

The Division of Mines of the Philippines will shortly issue a colored geological map representing the present state of knowledge of the geology of the Archipelago.

Mr. F. A. Dalburg, coal engineer in the Philippine Division of Mines, has gone to Spitzbergen to become superintendent of a coal mine.

Mr. R. A. Rowley, assistant professor of geology in the University of the Philippines, has recently returned from an expedition to the northern part of the Island of Palawan, and is engaged in working up a suite of rocks from that little known region.

CHARLES T. KIRK (Ph.D., Wisconsin, 1911) has been appointed professor of geology in the University of New Mexico. During the past summer he has done reconnaissance work on the Natural Resources Survey of the State of New Mexico.

MR. LLOYD B. SMITH, professor of geology in the Carnegie Institute of Technology of Pittsburgh, Pennsylvania, has resigned to enter the employ of the Associated Geological Engineers in the examination of oil and gas properties. With Mr. Frederick G. Clapp and Mr. Myron L. Fuller, he has gone to New Brunswick to investigate properties in that province. Mr. L. G. Huntley, also of the firm of Associated Geological Engineers, has returned to the Pittsburgh office after an absence of two months spent in geological examinations in the Athabasca River country in northern Alberta.